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Operational decision making in the U.K. furniture industry.

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OPERATIONAL DECISION MAKING IN THE U.K. FURNITURE INDUSTRY

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OPERATIONAL DECISION MAKING IN THE FURNITURE INDUSTRY

CONTENTS PAGE:

SUMMARY

Motivated to a large extent by the necessity to make a profit, the Furniture Sector of the U.K. economy provides an extensive variety of goods in an attempt to satisfy consumer demand. In the course of producing these goods, the Furniture Manufacturer faces numerous decision problems across the many differing aspects of the business activity. Two major decision problems which each Furniture Manufacturer faces are related to the purchasing and sub-division of chipboard; the major raw material cost element, namely:
The Assortment Problem and the Two-Dimensional Cutting Problem.

This research is therefore directed towards operational decision making in the U.K. Furniture Industry with specific emphasis towards the primary conversion operation carried out by the flat panel furniture manufacturer; ie. the well known Two Dimensional Cutting Problem. In addition, given that the type of sawing machine which is available can have a significant effect on the outcome of the cutting problem, the decision relating to the purchase of the sawing machine is also detailed.

OPERATIONAL DECISION MAKING IN THE FURNITURE INDUSTRY

INTRODUCTION:

The manager of today operates in a rapidly changing environment, where the decision situations encountered range from well structured, routine decisions to those which are fuzzy or ill-defined. To assist the manager in the decision making process a number of new approaches and techniques have been developed. In addition, many techniques have been extended and enhanced, due in the main, to the rapid and significant development of high speed, low cost computing facilities. Not withstanding these advances, management is still an art, - where art is defined as the skillful application of a body of knowledge - and must always remain so to a large degree. This is not to suggest that the advancement of the more quantitative, computer orientated approaches to managerial decision making have no contribution to make, they most certainly have. Given the consequences of inaccurate judgements, in the complex business environment of to-day however, far more is demanded and expected from these new managerial techniques.

One of the critical aspects of any organisation's environment is the state of the technology which effects it. Hence there has always been a strong tie between business and technology. It is self evident that businesses that wish to survive in an ever changing world, must keep abreast of the technology available to its products, services and to its methods of operation. Not surprisingly, the changes in technology, for a company or specific industry, will also have an impact on the practise of management. The change in technology can effect all the areas of the business function; not only in the planning and the design of products and services, but also in the ways to develop, produce, distribute and manage new innovations. For example, in the last thirty five years, the U.K. Furniture Industry, from its origins as a craft based industry, has undergone significant changes in the technological area of manufacture. This has required decision makers within the furniture industry to adopt and adapt different managerial styles to decision making, rather than just relying on their entrepreneurial flair and ability.

Motivated to a large extent by the necessity to make a profit, the Furniture sector of the U.K. economy, provides an extensive variety of goods, in an attempt to satisfy consumer demand. In the course of producing these goods, the furniture manufacturer faces numerous decision problems across the many differing aspects of the business activity. Two of the major operational decision problems faced are related to the acquisition and sub-division of the major raw material, chipboard, ie:

(a) What size and quantity of chipboard sheets should be ordered and stocked ; the Assortment Problem

and

(b) Given the chipboard stock sizes, quantities and the panel order requirements; panel lengths, widths and quantities, determine the cutting patterns required; the Two Dimentional Cutting or Trim Problem.

ECONOMIC IMPLICATIONS

On initial inspection the Furniture Manufacturer's trim problem does not appear to be a critical managerial decision area. On closer inspection and analysis however this is not the case. Economically, the decision on how the large sheets of chipboard are to be subdivided, so as to match the panel order sizes and quantity requirements, is important for two main reasons:

(1) The cost of the chipboard raw material is by far the largest element of the total manufacturing cost of the flat panel furniture product. Savings in material usage; ie a reduction of the wastage associated with the conversion process, could therefore result in economic benefits to both the manufacturers of furniture and to their respective customers.

(2) In addition, savings in material usage, in the

manufacturing chain, would require less chipboard substrates to be imported and hence reduce the importation cost of these materials. For example, table 1.0 indicates the consumption of particle substrate board and other sheet type material in the U.K. from 1975 to 1980. If by the exercise of greater managerial control, in the conversion process, a 3% saving in material usage was achieved this would result in a total direct saving of approximately two million pounds sterling, on importation alone. (see table 1.0). Similarly a Furniture company with a turnover of £8.5 million and a corresponding raw material chipboard cost of £1.4 million would show a saving in the region of £42,000 p.a.

Year	Actual importation in value terms mil	Reduction by 3% estimated saving mil
1975	46.5	1.39
1976	62.2	1.86
1977	64.9	1.94
1978	79.5	2.38
1979	82.6	2.47
1980	70.0	2.10
Estimated saving on importation costs p.a. £2.10 mil		

(Source FIRA Sept '82)

TABLE 1.0 ESTIMATED SAVINGS ON IMPORTATION COSTS

ORIENTATION OF RESEARCH

As the figures in the above table show, the conversion operation, in the manufacture of furniture is one of the key areas in the production cycle of flat panel furniture and has obvious economic implications for the furniture manufacturer and the economy alike. This research is therefore directed towards managerial decision making in the U.K. Furniture Industry, with specific emphasis towards the primary conversion operation of the flat panel furniture manufacturer; ie THE TWO DIMENSIONAL CUTTING PROBLEM. In addition and as a direct result of the main area of the research, the strategic decision related to the acquisition and purchase of the sawing machinery, which is used in the primary conversion operation is also detailed. Briefly this thesis is divided into the following ten chapters:

CHAPTER 1. Development of the Furniture Industry:

This chapter sets the research area in an industrial context by detailing the changes that have taken place since 1880; namely the changes in the use of materials; of the different approaches to manufacturing and the changes that have taken place in the practise of management.

CHAPTER 2. Approaches to the Cutting Stock Problem:

Initially this chapter describes the related operational decision problem of which stock sizes should be ordered? (the Assortment Problem) and the resultant Trim Loss Problem. The remaining contents of the chapter concentrates on reviewing the current approaches to the 1 and 2 D trim loss problems, given in the literature.

CHAPTER 3. TOWARDS A CONCEPTUAL MODEL OF THE FM 2DCP:

In many cases little time or space is given to detailing the formulation stage of the problem. This is not very surprising as writing up the travelogue which describes and supports the current solution procedure is exceedingly difficult. This difficulty is in part due to the fact that problem formulation, in many circumstances, cannot be achieved by following a set of structured, pre-conceived ideas. In many practical situations, the initial and probably the most important stage in problem formulations, is the requirement to think through and sort out the actual problem. This, however, is often difficult to do unaided. Chapter 3 then details the approach to problem formulation adopted in this research.

CHAPTER 4. Detailed Evaluation of the 2DC Problem:

In this chapter. the primary variables of the Furniture Manufacturers 2dc problem. as detailed in chapter three. are further detailed and evaluated..As can be seen from this evaluation stage of the research. the Furniture Manufacturers 2dc problem is not a single criterion decision problem based on waste alone but rather a multi criteria decision where waste costs are only one of the issues that are required to be considered.

CHAPTER 5. The Planners Decision Making Process:

In the light of chapters three and four, chapter five examines the manual methods and approaches adopted by Planners at structuring and solving their multi criteria 2dc problem. Currently much of the Planners knowledge base is ill-defined and operates at a subconscious level and hence has seldom, if ever, been documented. In this Chapter therefore we identify the major goals that the Planner uses in solving his cutting problem.

CHAPTER 6. Problem Formulation : Model Structure:

It is clear from the lack of successful implementation that trim problem solutions based on the waste criteria alone do not represent the real world problem. In this Chapter therefore we re structure and formulate the real world cutting problem of the Furniture Manufacturer.

CHAPTER 7. Problem Formulation : Proposed Solution:

In this chapter a heuristic search and problem reduction approach solution procedure is proposed and detailed.

CHAPTER 8. Evaluation of the Proposed Method:

The proposed method of Chapter 7 is evaluated against the normative LP cutting solution. The results indicate that the concept of User directionality; the use of User Defined and the facility to Rewind to any level - offer a marriage between the Users prior knowledge base and the conputational efficiencies of the computer that the LP approach cannot match. Although higher in pure wastage terms, the cutting patterns generated by our proposed method reflect in a more robust way the Planners actual decision problem and as such the results are more acceptable to the Planner.

CHAPTER 9. The Saw Purchase Decision:

Chapter nine addresses the Saw Purchasing Decision that is faced by the Furniture Manufacturer. Although initially it appears unrelated to the actual cutting pattern problem this is not the case. Attention to detail, by the Furniture Manufacturer, when considering this machine purchasing decision could result in considerable cost reductions in material utilisation.

CHAPTER 10. Conclusions:

The final chapter identifies a set of conclusions which although specific to the problem under analysis are also relevant across the many boundaries of managements activities. As these conclusions and the suggestions for additional research underline, it is necessary to understand the technical aspects of the problem as a pre-requisite to being able to provide solutions which match the real world problem.

In concluding this introduction it is perhaps appropriate to add the following:

The methodology adopted in this research is pragmatic in both style and content. It initially concentrates on discovering the nature and understanding what the problem is, rather than trying to change the problem so that it can be solved by known modelling techniques. Significant space is therefore devoted to:

(1) Detailing the historical background and understanding the industrial characteristics that the problem resides in.

(2) Analysing and structuring the actual problem from the base created by (1).

(3) Evaluation of the proposed solution method.

Although such an approach is most certainly not new, it is perhaps a timely reminder of the continued necessity for management to think what to think about when confronted with operational decision problems, rather than just relying on the application of well tried solution techniques alone.

CHAPTER 1. THE DEVELOPMENT OF THE FURNITURE INDUSTRY

1.0 Historical Background:

Although furniture making is one of the oldest crafts in the country, it is only the last one hundred years that the industry has in any sense become organised. It was not until the introduction of machinery towards the end of the eighteenth century that factories began to develop and production on a larger scale was attempted.

In 1880, although rudimentary sawing and planning machinery had been invented almost all cabinet furniture was made by hand. As Radford (1) notes:

> "................ steam powered saw mills were only beginning to replace the pit sawyers and the rough sawn boards were still delivered, by hand, or horse and cart to the workshops."

In the fifty years from 1880, steam power gave way to electric power and woodcutting machinery was available not only to saw and plane but to mould and cut joints as well. As with other aspects of the industrial revolution, it was the application of power, derived mainly from coal, which brought about the momentum for change. One of the casualties of this change process was the gradual closure of many of the craft based workshops. Craftsmen who were at that time specialists: Sawyers; Carvers; Turners; Cabinet Makers and French Polishers, either drifted away from their respective artisan craft or chose to stay and to form the new industrialised factory concept that became the basis of todays furniture industry.

From a raw material point of view, up until the 1880's the main raw material had been solid timber. During the 1880-1920 period however, Plywood became the important material in cabinet construction and had replaced solid timber for such parts as carcase backs and drawer bottoms. Little change in the raw materials took place during the period 1920-1940. Furniture continued to be constructed with Plywood which was supported by solid wood framing.

1.1 Post War Developments : 1946-75

In 1946, with the advent of peace came a high demand for furniture from newly married couples and from people rebuilding their lives after the war. As one can imagine, timber was in short supply; almost unobtainable. This prompted the government of the day to set up a council to advise on the design of furniture which could be produced quickly and cheaply, using the minimum amount of wood; the UTILITY FURNITURE CONCEPT. With this as the backcloth and with the worlds economies geared towards more peaceful activities, the first steps in furniture research and development were taking place that would later revolutionise the furniture industry.

1.1.1 Material Development

As an alternative to the plywood and timber framed construction of cabinets, the product Blockboard was developed and introduced in 1945-46. Although initially appearing to offer the Designer a stable panel material in almost any thickness, this otherwise excellent idea suffered from two major drawbacks, namely:

(a) The high cost of manufacture.

(b) The tendency for the strips within the core to show or telegraph through onto the surface finish.

It was on Blockboard however that the Furniture Industry had its first early experiences of dealing with flat panels. For the Designer, Blockboard although expensive, offered a thick, rigid panel material, which made it possible to construct a cabinet without internal framing or wood jointing. By 1947, the first large scale Chipboard Plant, the Mende Plant near Hannover, became operational. Once the early problems, such as variable density/thickness and instability, through poor moisture control, were overcome, an inexpensive material, suitable for the mass production of furniture was available.

When first used by the furniture industry, Chipboard was regarded as an inexpensive core material which had to be surfaced by real wood veneer or plastic laminates. In addition, the edges of the Chipboard were often reinforced by solid wood lippings so that the strength of the joints between panels of the carcase and the door hinge fixing depended upon the wood lipping and not the Chipboard core material. Given that the Chipboard materials thickness could and often did, exhibit large fluctuations in thickness it was also necessary to sand the lipped panels prior to the bonding of the surface skins. Recent improvements in the properties of Chipboard now make it possible for the use of thin paper to be directly applied to the surface of the Chipboard without any sanding operation being required. In addition, with the introduction of special fittings that were no longer required to be end grain located, the requirement for a solid wood edge lipping has all but disappeared. The result is that Chipboard type material now forms the major raw material of the furniture industry.

1.1.2 Machinery Development

Production of this new material, Chipboard immediately brought about new developments in many areas,

For example:

(a) The introduction of the wide belt sander to cope with the variability in the Chipboard thickness.

(b) Advances in adhesive technology were required for bonding the veneers and the thin paper foils to the Chipboard.

(c) Hot pressing techniques and the development of new melamine impregnated papers, ie Melamine Faced Chipboard.

(d) Design of new furniture fittings. The old methods of carcase assembly by screwing, nailing, dove-tailing and lipping were no longer relevant to the flat panel. As a result a new range of furniture fittings were designed.

(e) In the machinery area the availability of board type materials has resulted in the development of advanced machinery for cutting, edging drilling and insertion machines.

1.1.3 Marketing

From a marketing viewpoint, the arrival of the flat panel concept heralded the birth of the do-it-yourself flat pack furniture kit. A point to note is that all the previous materials and machinery developments were required before the home assembly market could start.

1.1.4 Management

As can be seen from the changes stated above, there are considerable differences between the current materials and machinery which are used by the present day furniture manufacturers and their predecessors. The modern furniture factory which is equipped with the latest type of machinery is capable of producing a high quantity of panels, (piece parts) in a very short time span. The adoption of these new technologies has also brought about many resultant operational decision problems for the individual furniture manufacturer and the industry as a whole. For example, questions which relate to which marketing and manufacturing philosophies should be followed are required to be addressed: The question of which managerial control systems ought to be used requires to be thought through: and the question of the necessity to carry high stocks of finished goods, or high work in progress, so that the customer can obtain immediate delivery, also requires an answer; From a material control and utilisation viewpoint, for the first time, the question also arises; How to calculate and draw out cutting patterns.

1.2 The U.K. Furniture Industry 1975-1980

From its origins as a craft industry then the U.K. Furniture Industry has undergone significant and tremendous change. The industry can now be characterised by two specific groupings, namely:

1.2.1 Group 1

A collection of small manufacturers with turnovers between 0.5 - 3.0 million, who take approximately 12% of the total domestic market but who represent 70% of the total number of manufacturing companies. This group can be characterised by their use of traditional skills in wood by the use of basic woodworking machinery. The manufacturing premises are likely to be old and not generally ideal for the current manufacturing activity being performed. Their market outlets are likely to be the specialist markets rather than the multiples, discount houses or mail order companies.

1.2.2 Group 2

These are the larger manufacturing companies with turnovers from 4 to 60 millions. The larger members of this group have sophisticated plant and adopt an engineering approach to the manufacturing process whenever possible in preference to a craft approach. The major raw material used is more likely to be based upon a combination of Chipboard, Flaxboard and other sheet materials, rather than on the usage of solid wood. Sales are mostly to the larger retail outlets, the multiples, discount houses and the mail order companies.

Although both groups are important, in as much as they offer a complete range of furniture products to the public, this thesis is directly concerned with the trim problem as experienced by the Furniture Manufacturers, in Group 2. At this juncture therefore the industrial background is continued by detailing the manufacturing cycle and the differing manufacturing philosophies that are available to the Furniture Manufacturers, who are members of Group 2.

1.2.3 Summary of Group 2's Manufacturing Cycle

In manufacturing terms there are three specific functional areas within the production cycle of furniture:

AREA 1. THE MILL: This in effect is the heart of the system. The area in which raw material, predominantly of board type, is converted into the specific sizes which enable particular furniture models to be manufactured.

AREA 2. THE POLISHING SHIP. This is the area in which the converted raw materials are polished thereby effecting the finished appearance of the furniture. It should be noted that dependent upon the type of finish the polishing function may be carried out in the Mill. In this situation, where melamine pre-finished board substrates are used, the polishing shop is likely to be very small and may very well only have hand spraying type operations left.

AREA 3. THE ASSEMBLY SHOP: This is the area in which the in-house manufactured panels, (parts) and the bought in parts, (trims, glass) are assembled together to effect a complete piece of furniture. Note, with the advent of the flat pack do-it-yourself furniture concept, packing stations replace the assembly shop. The production cycle of a typical Furniture Manufacturer, in Group Two, can be represented as shown in figure 1.

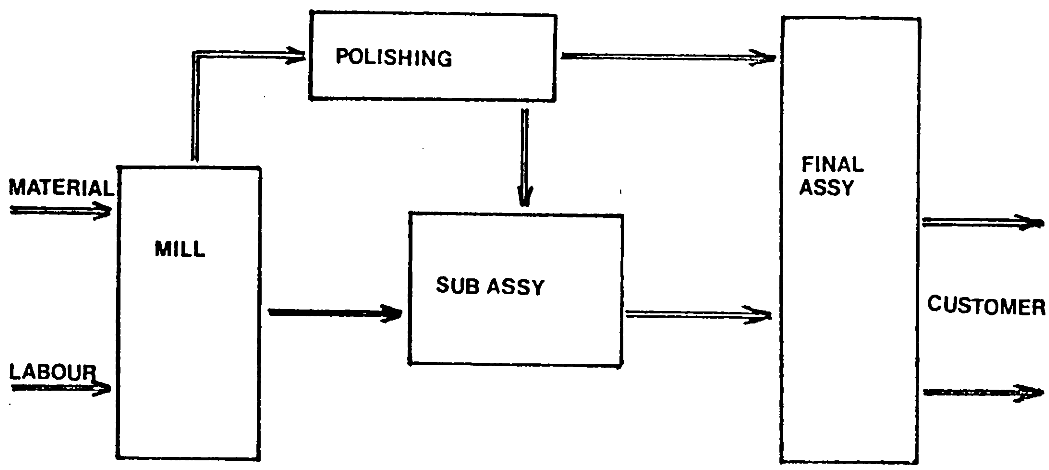


FIGURE 1.0 FURNITURE MANUFACTURING CYCLE

Although only a simple generalisation, the previous description of the manufacturing cycle serves to identify the three main functional areas within the production cycle of furniture. All the areas are deemed to be important, as they interact one with another, towards the overall goal of furniture production and profitability. Given these goals the Mill is viewed as being of critical importance. The main reasons for this asertion are as follows:

(a) For most furniture companies, the purchase of raw material constitutes a considerable sum of money - often the largest proportion of the total manufacturing cost. Decisions in the raw material area therefore have a greater effect on the profitability of a company than any other single variable.

(b) The Mill initiates the whole system by converting the raw materials - Chipboard, Flaxboard and other sheet materials - into manufactured panels. Upon completion of this primary conversion operation, the panels are then subjected to additional machining operations such as edge banding, drilling and fitting insertion. These additional operations are sequential in nature and as such minor incorrect decisions vis-a-vis sequencing, setting time, volume throughput, which occur in the Mill, often become major issues, further down the manufacturing chain.

1.3 Approaches Taken in Manufacturing Control

Within the U.K. Furniture Industry it is possible to identify three different order control approaches that are used in the manufacturing cycle, namely:

* MAKE TO ORDER
* MAKE TO STOCK
* THE INTERMEDIATE APPROACH

These three approaches to manufacturing are now described.

1.3.1 Make to Order:

This approach is favoured by the smaller Furniture Manufacturer. In general, the furniture company waits until an order is received from a customer before initiating the start of the manufacturing cycle. Although this method of manufacturing has the over-riding advantage that the risk of over or under producing is virtually eliminated, it does contain the following limitations:

(a) There is a requirement to hold adequate raw material stocks to meet 'likely orders', whilst being at the mercy of suppliers lead times for specialist materials and or parts which fall outside normal stock ranges.

(b) The requirement, due to continuing product design changes within the market place, to have a skilled and flexible labour force.

(c) In following this manufacturing order approach, the bursts and lulls of activity; ie. seasonal fluctuations in the order intake, result in the necessity to either work excessive overtime or to lay off the labour force. The result is that there is little stability for employee or employer.

1.3.2 Make to Stock:

This approach is followed by the larger furniture manufacturers who, due to their higher turnovers, offer a much greater variety of furniture models to the retailer, (generally public). The number of times a specific product can be manufactured is therefore limited by the manufacturing capacity, which controls the cycle time of the number of batches that are possible. A significant issue for most Furniture companies who follow the 'Make to Stock Approach' is that such an approach demands the ability to be able to forecast future sales trends to some degree of accuracy. The Make for Stock approach therefore contains an element of risk, due to the uncertainty associated with the following external market demands; eg. consumer demand; economic trends; government legislation; credit restrictions. In addition a further point which adds further complications is the risk of obsolete stock - as some manufacturers can testify to.

The major advantage often cited for the Make to Stock approach is the benefits of steady production. This advantage, however, has to be viewed against the following requirements:

(a) The necessity to obtain high utilisation from machines and labour.

(b) The requirements for low rates of investment such that stock holding costs remain realistic.

(c) The necessity to have good control over the purchasing, production and distribution functions. These requirements for 'control' are more necessary in this approach because of the high volume of material usage.

1.3.3 The Intermediate Approach

Some furniture companies who are neither impressed by the boom, lull fluctuations, which arise in following the 'Make to Order' approach, nor the high amount of capital that is often required to finance the stocking policies of the 'Make to Stock' approach attempt to slot between both the approaches. They do this by adopting a two stage approach to the manufacturing cycle. The first stage requires a batch of

'SIZED PANELS', to be produced. These panels are held at a specific assembly level, in an intermediate panel storage area. The second stage is initiated when the customers order(s) are received. The customers orders are grouped together to form a batch requirement and then exploded into the part requirements; - bought out components and in-house manufactured parts. The intermediate panel storage area is then checked against the panel order requirement listing. If the panels are available they are withdrawn from the panel stock and the necessary operations carried out so that the furniture model can be completed. If there are panel types lacking within the panel requirement listing then a new panel order set is initiated by the Production office.

In essence the Mill behaves like a large circulating pump, continually receiving demands, ascertaining the requirements for the whole system and executing the order requirements to ensure that the whole system remains balanced. The simple, although difficult to achieve requirements in following this approach, is to have limited variety in panel sizes, preferably designed to specific board sizes which in turn equate to simple cutting patterns, all of which should be coupled to a good production control system. Given that these conditions are satisfied, the major advantage to be gained from this approach to manufacturing order control are:

(a) Lower work in progress.

(b) Reduced cycle time of the batch. This is due to the Mill being continuously loaded, irrespective of the system in general. This in turn minimises set to run times of the machine groups in the Mill, thereby increasing the volume throughput which has the effect of reducing the unit cost of production.

(c) It follows that companies who adopt this approach have the majority of their stock cost in the form of semi-finished panels. Hence there is a requirement for a good stock control system which accurately records the day to day debits and credits of the panels that leave and arrive in the intermediate panel storage area.

1.4 Summary

This profile of the U.K. furniture industry identifies the following facts:

(a) There has been significant change within the U.K. Furniture Industry during the last thirty years. The industry has moved away from the craft dominated approach to what can only be described as an "engineering" approach to furniture manufacture.

(b) There are two distinctive groups within the U.K. Furniture Industry, each serving different markets and following different manufacturing control orientations in an attempt to satisfy their respective customer groupings.

(c) There are three functional areas in the manufacturing cycle of furniture production, namely: The Mill: The Polishing Shop; and The Assembly

Shop. Although with the continued technological advancements made in the material and machinery areas, ie. man-made melamine impregnated paper foils and fast flow process lines these latter two areas are slowly decreasing in importance.

(d) As a result of the changes in machine technology the labour content in furniture manufacturing has been significantly reduced. Raw material costs on the other hand have continued to rise. The end result being that the operational decisions relating to raw material purchase and utilisation are now of critical importance. This thesis is concerned with one of these key operational decision problems, namely :

THE FURNITURE MANUFACTURER'S TWO DIMENSIONAL CUTTING PROBLEM.

Currently the task of generating cutting patterns, in the U.K. furniture industry, is carried out manually. This manual approach to the problem initially appears rather surprising, given that there is an extensive body of literature purporting to have solved the cutting stock problem. Our starting point in this research therefore was to conduct a review and analysis of the previous approaches and publications in the area of cutting stock problems. The objective being to discover why the computerised approach to the cutting stock problem had found little favour with the planners in the furniture industry.

CHAPTER TWO. REVIEW OF THE RECENT LITERATURE.

2.0 The Furniture Manufacturers Cutting Problems

Prior to reviewing the trim problem solution strategies, as detailed in the literature, the two different cutting stock problems that confront the furniture manfuacturer are briefly outlined, ie.

(1) - the Assortment Problem: ie What initial stock sizes / quantities should be ordered?

and

(2) - the Cutting Stock or Trim Loss Problem: ie. Given the stock sizes/quantities and the panel order requirement, what stock board sizes should be used and how should they be cut?

The Assortment Problem

The Furniture Manufacturer's assortment problem is constrained by a combination of marketing characteristics, machining limitations and purchasing difficulties. For example, although the simple answer may be to design panel sizes so that they match standard board sizes, the marketing price point value concept, which correlates specific furniture model sizes to retail prices, results in panel dimensions not being a factor of the standard board size. The technological limitations arise due to the actual chipboard press size, which limits the initial chipboard sheet size to being very large, approximately 10/12 metres or very small, 3.5 metres. Given that the large board size will cause difficulties in both chipboard and furniture factory an initial sub-division of the board is completed by the chipboard factory, sheet sizes in the Furniture factories. When these factors are added to the necessity for the Purchasing function to be working up to six to ten weeks ahead on exceedingly flimsy sales order forecasts, then it becomes plain to see that the assortment problem is difficult to structure in a practical sense. In addition, given that the sales order forecast does not become 'firm' until the last possible moment, the ability to offer a solution to the assortment problem is often not possible due to the lack of adequate data on the panel sizes/quantities required.

In practise the solution adopted to the Assortment problem, given the above circumstances, is for the purchasing department, in conjunction with the design and sales order departments, to place orders for the large chipboard sheet, L to be sub-divided so that two of the resultant board sizes; L1 and L2 are identical with L3 being the 'faller'. eg. given an initial board size of 10 metres, then L1 and L2 would be 3.5m and L3 would be 3.0 metres. This board division is illustrated in figure 2.0. In general the purchasing department is solely concerned with global material unit costs and as such the size of L and L1/L2 are related to the largest panels that are required by the furniture manufacturer. The result of this pragmatic purchasing approach is that waste minimisation; the utilisation of materials, is not specifically considered until the cutting patterns are generated by the Planner.

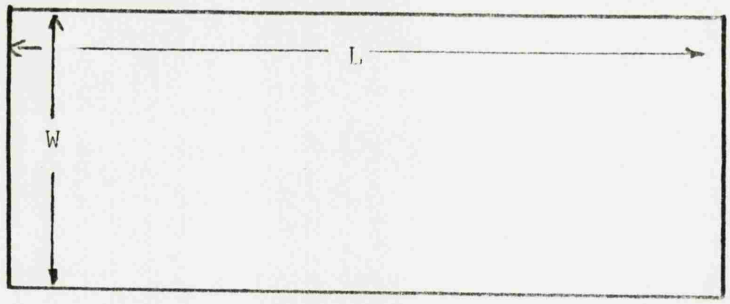
The Two Dimensional Cutting Problem

The two dimensional cutting problem arises in the manufacture of furniture due to the advances made in materials and machine technology. Without the development of chipboard and the subsequent sawing technologies, furniture would still be manufactured from solid timber and the two dimensional cutting problem, (2DCP) as such would not exist. The starting point of the furniture manufacturers 2DCP then is the information relating to the stock sizes and quantities of the chipboard that are available and the details of the panel order requirement. Once this data is known the Planner can generate cutting patterns. These generated cutting patterns are the blueprints from which the large chipboard stock sizes are sub-divided, by various sawing and sizing operations, to match the panel order requirement, according to manufacturing demand. Hence the 2DCP is the first entry point where it is possible to offer assistance which would enable the furniture manufacturer to obtain the minimum total cost associated with the raw material conversion operation.

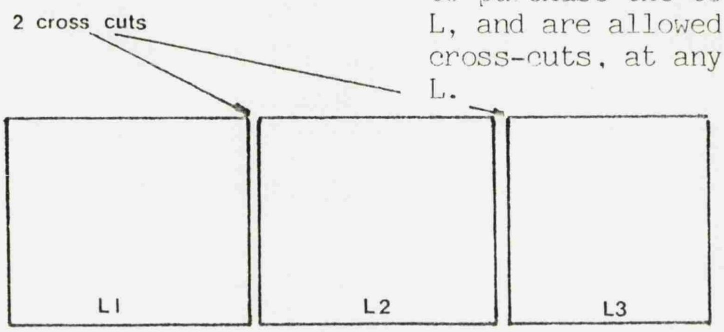
Given the significance of the chipboard raw material cost on the unit price this latter cutting stock problem of the furniture manufacturer is of critical importance. Failure to monitor and control the material utilisation can result in serious detrimental affects on profitability. For example, the cost of chipboard for a furniture manufacturer with a turnover of £6 million is approximately £1.25 million. A 1% increase in chipboard utilisation equates to an increase of £12,500 in profitability. This saving correlates to an increased sales volume of 1,250 standard wardrobes. ie. the profit on a standard wardrobe is in the region of £10.00. This research therefore is centred on the furniture manufacturer's trim loss or two dimensional cutting problem.

Prior to reviewing the literature in the area of cutting stock problems the inter-related nature of the furniture manufacturer's cutting stock problems are now diagramatically illustrated:

1.L and W are functions of the chipboard and machinery design.

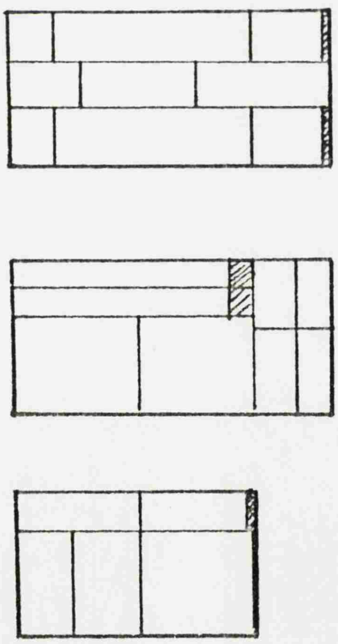


2. In general, the Furniture Manufacturers are required to purchase the total length L, and are allowed two free cross-cuts, at any position on L.



3. The initial large chipboard sheet, L x W sub-divided by two cross-cuts, C1 and C2.

4. Resultant is three board sizes (L1 x W:L2 x W:L3 x W)



5. These smaller boards of length L1:L2:L3 are further sub-divided by the Furniture Manufacturer, to match the panel order requirement sizes and quantities. The shaded area represents edge waste.

FIGURE 2.0 DIAGRAMATIC REPRESENTATION OF THE FURNITURE MANUFACTURER'S CUTTING STOCK PROBLEMS.

2.1 CUTTING STOCK PROBLEMS: REVIEW OF THE LITERATURE

The majority of the published work to-date has focused attention on the One dimensional trim problems of the Paper Industries, (2, 3, 4) and the Two dimensional trim problems of the Glass, (5, 6) and Steel, (7, 8) industries. Only minor reference has been made to the Furniture Industries Two dimensional trim problem in the papers by Christofides and Whitlock, (9) and Pfefferkon, (10). The emphasis in the majority of the published work has been towards defining the problem in terms of the mathematical solution methods adopted. The exceptions being the survey of the trim-loss and assortment problems by Hinxman, (11), the application paper on the (failure) of O.R. in solving the trim problems in the Paper Industry, (12) and the associated methodology of reporting O.R. by Stainton, (13) which restructures an earlier cutting stock problem related to the Steel stockholder.

The solution methods cited in the current literature for the One dimensional (1d) and the Two dimensional (2d) trim problems can be divided into the following two groups:

(1) ALGORITHMIC:

(2) HEURISTIC :

Before these two solution approaches are detailed however, the solution cited in the literature for the 1d trim problem is reviewed. The major reason for this slight detour is that many of the suggested solution strategies for the 2d cutting problem emanate from the 1d case.

2.1.2 REVIEW OF THE ONE DIMENSIONAL TRIM PROBLEM

The first recorded algorithmic approach carried out on trim problems was by Kantorovich (14). In this early paper, Kantorovich described 1d and 2d cutting stock problems as one of several applications that had been solved by the use of an iterative algorithm. Much later, additional authors, (15) utilised this work base to formulate linear programming models for the Paper Industries 1d cutting problem.

These LP models are based on the following general equation:

$$V = \sum_{j=1}^{n} r_j \quad x_j \rightarrow \min \qquad \ldots\ldots(1)$$

under the condition that

$$\sum_{j=1}^{n} a_{ij} \quad x_j >= k_i \quad \text{for } i=1\ldots.m \text{ and } x_j >= o \quad \ldots.(2)$$

where a_{ij} represents the number of orders of type i cut in the cutting combination j.

k_i represents the required order quantity of the order i.

r_j represents the trim loss in combination j.

x_j represents the number of cutting patterns cut, defined by the combination j.

and V represents the total cut wastage or trim loss.

This model formulation however soon caused computational difficulties for the early practitioner. The main difficulty being that even for a small cutting stock problem the number of possible combinations and hence columns within the LP matrix are extremely large. For example, see the six order cutting stock problem given by Haley (16) which results in twelve equations and one hundred and six variables within the linear programme tableau. These computational difficulties only increase when there is no grain direction to be considered. In such cases the potential number of combinations to be considered increases significantly (17).

Further methodological difficulties may also arise given that the possibility also exists for degeneracy to occur in the final solution tableau. ie. more than one optimal solution is present. See for example the Trim Loss problem given by Vajda, (18) which illustrates three equal minimum waste solutions for the same problem. Vajda's statement, page 59, that .. "All three are optimal solutions with the same total edge trim " is only correct if the decision criterion being used by the Planner is waste minimisation only. If wastage is not the only objective function, then the problem exists of how the Planner selects from the three alternatives which exhibit the same wastage levels? Whilst it is tempting to suggest that there are no differences between the three cutting patterns, this is not necessarily the case. In practise, where degenerate solutions exist, other decision criteria are required to be incorporated into the solution model thereby enabling the successful solution to be determined.

2.1.3 SOLUTION FOR THE 1DCP : GILMORE AND GOMORY

In an effort to overcome these and other computational difficulties a proposal was made by Eiseman (19) whereby only a library of 'good' columns would be generated. The difficulty however was to determine measures of 'good' that sufficiently restricted the size of the matrix without distorting the eventual solution. Additional proposals by Metzger (20) and Eilon (7) also failed to increase the size of the problems that could be dealt with using the standard LP approach. It was not until the pioneering computational work by Gilmore and Gomory, (21 and 22) that solutions for large scale 1d cutting stock problems became practical. Their method of solution required the solving of an auxiliary knapsack problem to determine the successor solution, at each stage of the simplex tableau. Basically, simplex steps and knapsack steps follow one another until the solution cannot be improved. This proposed solution strategy, however, as noted by Kuutti and Voutilainen, (23) and recently acknowledged by Gilmore (24) depends heavily upon being able to rapidly solve knapsack problems.

From a practical point of view, the usage of computer based solutions to the 1d cutting problem based upon the Gilmore and Gomory method, has had little success, especially in the Paper Industry. The main explanations given for this are that:

(a) - the minimum run length for a cutting pattern cannot be specified within the LP formulation.

(b) - in the computerised approach the number of cutting patterns to orders are generally in the ratio of 1:1 and this is too high. The main reason why each panel order input results in a cutting pattern is due to the fact that each order effectively becomes a variable within the LP formulation and each variable is solved. ie. results in a cutting pattern. Recently backward searches have been utilised after the completed enumeration of the cutting pattern set, in an effort to combine cutting patterns that are similar or the same, (12).

It should be noted that in many manually generated solutions, Planners often achieve a reduction of some 30% on the number of generated cutting patterns to panel order inputs for a small increase in the material usage.

The goal, as pointed out by numerous authors, e.g. (3,4) is to find cutting pattern solutions which satisfy the practical requirements of high pattern run quantities and low number of actual cutting patterns which also have small trim losses. Clearly the use of the LP solution approach cannot reflect these non linear characteristics.

2.1.4 AN INTERACTIVE SOLUTION APPROACH

These practical difficulties, which have hindered the implementation of the computerised approach to the 1d cutting problem have generated many academic papers, discussions and potential solution strategies. For example, a method proposed by Kuutti and Voultilainen, (23) is based upon 'prior packing' the order sets which are compatible. ie. are the same dimensional size. This approach effectively reduces the actual order set that has to be considered by the LP which results in less cutting patterns being generated.

The major limitation to this approach however is that the combining of the orders, termed macro-modifications, is quite difficult, even at the one dimensional level. In addition, the efficiency of the proposed method lies in the combinational aspects of the actual paper orders rather than in a precise mathematical method. Although these two criticisms are not directly admitted to in Kuutti and Voultilainen's paper, a degree of User interaction has been included into their programme, NOPTRIM to take account of some User 'difficulties' eg.

- the User is able to select the macro-modification level for combining order sets.

- the User is able to select the branching route that minimises the deviation in the uses of the cutting patterns, (or can select to minimise the trim loss, one supposes?).

The success achieved in practise by this 'prior packing' approach suggests that the previously detailed residual problems have been overcome and no longer exist. Their implementation success however could also be due to the inter-active nature of the modelling approach, which makes best use of the combined capabilities of man and machine?

This brief detour indicates that even at the simplified 1d level, the cutting stock problem is not as easy to solve as it first appears. At this point we return to define the staged two dimensional cutting problem and to further detail the algorithmic and heuristic solution methods, given in the literature for the 2d cutting problem.

2.2 STAGED 2 DIMENSIONAL CUTTING PROBLEM

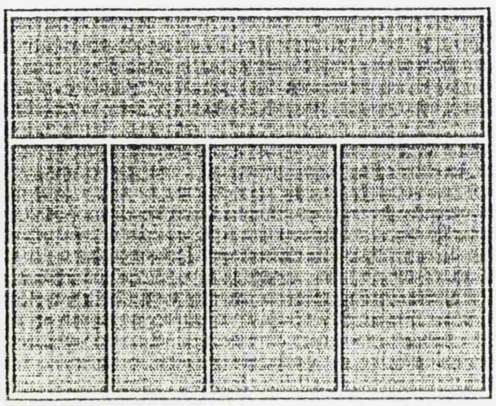
A staged two dimensional cutting operation can be defined as:

The manufacturer holds various rectangular/square board sizes from which will be cut a given quantity of specific rectangles of varying lengths and widths. The cutting operation of these order requirements is performed in a number of defined stages, namely:

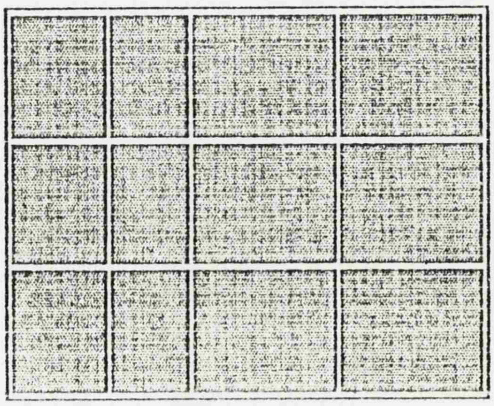
Stage 1. The stock board is cut across its length or width; in practise the length cut is normally carried out first so that a number of strips of width W (i) are produced. Due to the material (board in this case) and the cutting machinery used, the cuts must be guillotine. ie. starting at one edge of the material and ending at the opposite edge.

Stage 2. The strips generated from the first stage are subjected to a second guillotine cut, taken at right angles to the first stage cut. Normally only two cutting operations are required to effect the actual panel size. However, in the Furniture and Glass industries a third stage cutting operation may well take place. This third stage cutting operation is referred to as Z cutting.

Typical staged two dimensional cutting patterns are illustrated in figure 3.0



Single length and multiple cross - cut.



Multiple length and cross - cutting.
Checker board.

FIGURE 3.0 STAGED TWO DIMENSIONAL CUTTING PATTERNS.

2.3 ALGORITHMIC SOLUTION APPROACHES TO THE 2D CUTTING PROBLEM

There are three basic algorithmic approaches suggested in the literature for the solution to the 2d cutting problem. They are:

(A) THE ITERATIVE METHOD OF GILMORE AND GORMORY

(B) THE RECURSIVE ALGORITHM OF HERTZ, (25)

(C) THE JOINT BRANCH and BOUND/TRANSPORTATION ALGORITHM OF CHRISTOFIDES and WHITLOCK, (9)

Other authors, notably Marconi (26) and Dyson, (6) use adaptations of the now standard Gilmore/Gormory method. These three basic algorithmic approaches are now further detailed.

2.3.1 THE ITERATIVE APPROACH : Gilmore and Gomory

The 2d cutting problem can be formulated as a Linear Programme, with the objective function being to minimise the amount of trim loss. Given that the number of possible combinations become extremely large - which is the case, the number of columns within the LP are correspondingly large. To overcome this computational difficulty Gilmore and Gomory suggested a more compact approach which they called "a delayed pattern generation approach." This suggested approach reduced the necessity for all of the patterns to be generated in one matrix, rather at each iteration, an auxiliary knapsack problem which determined the successor solution, had to be solved, ie. a similar approach that they had used on the 1d cutting problem solution.

Not surprisingly, implementing this delayed generation approach, as noted elsewhere (12), requires one major problem to be overcome, namely the solution of a knapsack problem. Gilmore and Gomory suggest the following two methods for the solution of the knapsack problem: (a) a dynamic programming solution approach and (b) A branch and bound solution method.

As an additional note, the selection of the knapsack solution method usually depends on the nature of the problem itself. Hence there is often the necessity for the knapsack solution to be specifically formulated to match the industrial characteristics of the cutting problem. For example, Dyson (6) cites how a variety of industrial restrictions were required to be incorporated into a 2d cutting problem in the Glass industry. Similarly, the adaption by Marconi resulted in the inclusion of stock holding costs and the characteristics of the cutting machines being included in the knapsack formulation, (26).

2.3.2 THE RECURSIVE APPROACH : Hertz

The second approach detailed in the literature is the recursive algorithm of Hertz (25). This approach, however, is only valid under the assumption that there is no bound for the number of occurrences that a small rectangle can appear in the solution. In practise cutting problems appear in a constrained form. The most usual constraint being the one that restricts the maximum number of orders of each panel type required. Hertz argues that the assumption of having no bounds for the number of these smaller panels makes it possible to '.get rid of ' anisotrophy (non-symmetrical)considerations. Whilst this assumption is mathmatically correct, the result is that the recursive algorithmic approach advocated by Hertz is unusable.

2.3.3. JOINT BRANCH AND BOUND/TRANSPORTATIONAL ALGORITHM: Christofides and Whitlock

The starting point for Christofides and Whitlock (9) was the realisation of the non-linear constraints and characteristic that appeared in practise and the fact that these practical constraints cannot be taken into account when formulating the problem as a Linear Programme. The understanding of the non-linear aspects of the 2DCP led to the development of a solution strategy based on the following three stages approach:

Stage 1. An algorithmic procedure that generates a set of 'NORMAL' cutting patterns. (Normal being defined with respect to the order set and the current available board stock).

Stage 2. A method for implicitly enumerating these patterns in a general tree search algorithm.

Stage 3. The best feasible allocation of the order requirements to the board (stock) is then solved by a version of the transport routine (27).

This approach to pattern generation is satisfactory for the ones and twosey type of cutting problem only. The higher order requirements of the Furniture Manufatcurer precludes a 'series of cutting planes' approach as the resultant generated patterns - nodes to evaluate - would be prohibitive in computational time. In addition, the generated patterns would not reflect the sawing technology currently used by the Furniture Industry.

2.4 HEURISTIC APPROACHES TO THE 2 D CUTTING PROBLEM.

The heuristic approach is ideally suited to two types of problem, namely those that are too large to be solved by the application of the explicit operational research models and those that are too loosely structured to be expressed in the mathematical terms necessary for the traditional algorithmic solution methods. In addition and a point often overlooked, is the fact that heuristics are highly domain-dependent; ie. they use information pertinent to the problem to develop the solution. Hence, even superficially similar problems in the cutting stock area will probably require different heuristic approaches.

The heuristic solution methods cited in the literature for the 2d cutting problem can be classified into the following four groups:

(A) STATE SPACE SEARCH

(B) PROBLEM REDUCTION

(C) VALUE HEURISTIC

(D) CUT-OFF HEURISTIC

These four heuristic approaches are now briefly outlined:

2.4.1 STATE SPACE SEARCH

In a state space search approach, potential partial solutions to the problem are considered to be nodes on a graph. A search is then made for a path in the graph, starting at the initial state. The approach adopted appears to be very similar to the 'tree search approach' suggested by Christofides and Whitlock. However, not all the cutting pattern combinations are enumerated and as such the solution procedure is correctly termed heuristic. For an example of this approach see (28).

2.4.2 PROBLEM REDUCTION METHOD

In a problem reduction method, the initial problem is decomposed into smaller sub-problems, which in turn may be further decomposed. The solution of the original problem being formed by the joining of the solutions from the set of sub-problems, resulting from the decomposition. For example, a common form of problem reduction used in practise is that once a cutting pattern has been generated, it is used as many times as is possible. The only bound being that the usage of the cutting pattern should not create over production of the order. The order requirement list is then decremented and a new cutting pattern developed for the remaining panel orders. These steps are then repeated until the total order requirement is satisfied. This method, as noted by others, (12) allows the generation of feasible 2d cutting patterns, whilst allowing the industrial characteristics of the problem to be easily incorporated into the solution procedure. The main disadvantage however is the necessity, due to the sequential nature of the solution procedure, to make no mistakes in the decision on the current ' best cutting pattern ' to be used. Little information is given by the current literature on how the decision for BEST is arrived at.

2.4.3 VALUE HEURISTICS

If the only consideration in determining 2d cutting patterns were the material costs associated with the pattern, then the problem would be somewhat simplified. By taking the value of the panel to be cut to be proportional to its area, the waste minimisation problem could be formulated as one of maximising the value of the pieces cut. However, in nearly all practical situations it is not as simple as that. Firstly, there may be priorities on certain orders; certain panels, for example, may be required first due to their processing time. Certain panels may be required at the next operation together; eg. sides and ends for a plywood packing case box. In such circumstances, these non linear requirements can be heuristically assigned a value of their 'value importance' used in determining the best cutting pattern. Pegels (29) for example implicitly considers three value cost items; namely waste costs; set up costs of the machines and the opportunity cost of under utilisation of the machining capacity. Other authors (11, 2) also adapt and use the 'VALUE CONCEPT APPROACH' to suit their respective problems.

2.4.4 CUT OFF HEURISTIC

Where an algorithmic method is iterative, it may be converted to a heuristic method by causing it to terminate before all the iterations have been performed. The criterion for termination may be computational cost/time or it may be that the solution values produced by successive iterations are less than a set threshold limit. In such cases a cut-off heuristic approach has been adopted.

2.5 LIMITATIONS OF THE CURRENT SOLUTION METHODS

To be for or against either of the previously documented 2d cutting problem solution approaches is as sensible as being for or against screwdrivers! It is not about saying one technique is better than another. Each approach and the modification and adaptation that has followed, has assisted in expanding the knowledge and understanding about the 2d cutting problem.

Initially, the limitations in the algorithmic approach, pioneered by Gilmore and Gomory, were the number of patterns that had to be considered. Even with the improvements, brought about by the delayed pattern generation technique, which enabled one to implicitly consider all possible patterns whilst holding only a few at any one time, the results from such a mathematically orientated model did not reflect all of the industrial characteristics of the cutting problem.

Pierce (4) then was the first author to document a heuristic approach to solve trim problems related to the Paper industry. The realisation being that it was not possible to solve non-linear problems using Linear Programming techniques. More recently, the ingenuity of the heuristics methods suggests that it is now possible to consider the following industrial characteristics. when generating cutting patterns:

(a) restrict run lengths of the cutting patterns

(b) to include tolerance on the over/under production or orders.

(c) to explicitly control the number of cutting patterns to panel order inputs

However, as pointed out by Johnson (12) the major weakness of the current heuristic approaches is the fact that the cutting pattern enumeration and evaluation are carried out in two stages, with the result that the sequencing of the cutting patterns still remains a problem in many practical situations.

2.5.1 CUTTING OF STOCK - NOT A SINGLE PROBLEM.

According to the literature then, there are many solution methods available to solve the Furniture Manufacturer's 2dcp and yet few companies actually make use of computer generated solutions to solve their cutting pattern problem. In practice the majority of companies rely on the skill, knowledge and experience of their Planners who manually generate the cutting pattern set.

Whilst the manual cutting pattern sets do not result in minimum wastage, they are generally found to be within 1% - 2% of that figure. It became evident, when comparing the manual and the computer solutions, that the manually generated cutting pattern sets took into account other decision criteria than levels of waste. In effect Planners utilized their experience and understanding of their manufacturing environment to structure the cutting pattern problem so that 'intelligent' patterns which balanced the conflicting requirements of: low wastage: high volume: low number of cutting patterns and low order spread, were generated. The fact that the L P. approach has met with little success should be of no great surprise. Such an approach, which has been carried over from the Paper, Glass and Steel Industries does not reflect the decision problem faced by the Planners within the Furniture Industry.

Although wastage levels are of obvious importance, other operational characteristics and their implications are required to be taken into consideration and evaluated at the cutting pattern generation stage.

In practice Planners do not require a normative model which restricts and regiments their decision process to one of minimizing edge waste alone. Their requiremnt is for a decision tool whereby the conflicting requirements of the 2 DCP can be effectively structured and efficiently examined in detail. The main reasons for this lack of successful implementation is due to the fact that:

(a) The initial concept of waste minimisation is incorrect.

(b) The optimisation type model does not reflect the practical decision problem faced by the Planners; ie. the model is not robust enough.

(c) The lack of time and thought given to the model formulation stage. For example no information appears in the literature which suggests that the planners decision making process has been studied in any depth.

Given these conclusions, in the following Chapter we address the fundamental question of what the Furniture Manufacturers cutting pattern problem is about. Unlike most practitioners we are not prepared to accept, second hand, that the only definable objective function is the minimisation of waste.

CHAPTER THREE. TOWARDS A CONCEPTUAL MODEL OF THE FURNITURE MANUFACTURERS 2DCP

3.0 OUTLINE OF THE FURNITURE MANUFACTURER'S 2DCP

Little time or space is given in the published literature to detailing the formulation stage of the cutting problem. This is not very surprising as writing up the travelogue which describes and supports a proposed solution procedure is exceedingly difficult. This difficulty is in part due to the fact that problem formulation in many circumstances cannot be achieved by following a set of structured, pre-conceived ideas.

In many practical situations the initial and probably the most important stage in problem formulation is the requirement to think through and sort out the real world problem. This, however, is often difficult to do unaided. For example, the formulation stage of the Furniture Manufacturers 2DC problem proved to be exceedingly difficult, due mainly to the high number of variables and their inter-related nature. To overcome these 'processing difficulties', and as an aid in thinking aloud and structuring the problem, techniques developed by the Science & Decision Analysis Group at the University of Bath for exploring complex decision making problems were used.

For most furniture companies, the purchase and usage of raw materials, in particular chipboard type materials, constitutes a considerable sum of money and is therefore required to be minimised in the pursuit of profitability. To this end, Furniture Manufacturers purchase large quantities of chipboard, at various finishing levels, in a number of standard sizes, in an attempt to reduce the costs associated with material aquisition and stocking. These large rectangular/square stock board sizes are then converted by numerous machining operations into the required panel sizes, according to the specific 'panel order demand'.

The environment that the Planner is required to operate in will vary dependent upon the product orientations, the manufacturing processes and the marketing philosophy followed, irrespective of the differences that will undoubtedly exist between the different furniture companies. The Planning orientation followed, however, will be towards simple, robust solutions which satisfy the numerous competing objectives that are contained within the manufacturing environment. A typical approach, even in the larger companies, restricts the Planning Department's function to deciding an overall general operational plan. The emphasis being more on ' what is required' rather than ' how it is to be done'. For example, detailed operational requirements of machine loading or raw material availability is often delegated and dealt with by factory supervisory levels, rather than by the Planning department.

One area that the Planning department are required to consider both the 'what' and 'how' in is the conversion of the stock boards into the smaller panels: the 2DCP. The Planner is required to determine, consistently, a combination of cutting patterns which effectively balances the following operational cost areas:

(a) Edge waste costs.

(b) Cost of cutting.

(c) Volume throughput.

(d) Number of cutting patterns to panel order input.

(e) Handling and storage costs before and after cutting.

(f) The spread of a specific panel order across too many cutting patterns.

The overall goal of the Planner is to generate cutting patterns which satisfy some practical requirements, often production orientated, whilst balancing between the above cited operational cost areas, (a) through (f).

3.1 WASTE and other CONSIDERATIONS:

Management on the other hand nearly always judge the effectiveness of the conversion operation by the single variable of waste minimisation. Little, if any, attention is given to the other operational cost areas, (b)through(f). There are two main reasons for this, namely:

1 - A failure by management in the first instance to clearly understand the nature of the conflicting operational requirements contained within the 2dc problem boundaries. Hence management often evaluate the effectiveness of the conversion operation (in effect the performance of the Planner) by waste levels only. This measure of performance then is woefully inadequate. For example the Planner can, in an attempt to minimise edge waste, increase the complexity of the cutting patterns; ie. different trim types; mixing of different panel types in strips...etc. This increase in pattern complexity, although reducing the wastage level results in more time being required in the sawing operation. ie. a detrimental effect on the volume throughput which in turn increases the cost of cutting. In addition, the possibility also exists that due to the increased complexity of the pattern, storage and handling difficulties will also be experienced at the outfeed table of the sawing machine. The effect being that the volume cut in a given time is only further reduced.

From our detailed study of Planners in action we can state that Planners do not simply follow management's exact instructions to ..'minimise waste' but rather attempt to balance between the conflicting operational goals of (a) thru (f). The result being that the cutting patterns produced by the Planner, although operationally correct are sub-optimal, when judged against the managerially required goal of minimum waste.

2 - Despite the economic significance of the trim problem, management normally delegate cutting pattern determination to the lower levels within the organisation. Such a decision is only compounded when one realises that the Planner is rarely given the time or all the necessary information to evaluate the cutting pattern problem correctly.

3.2 APPROACHES to MODEL BUILDING:

The Furniture Industries 2dc problem then cannot be simplistically modelled by just minimising the trim loss in producing a set of panels from a known set of board sizes. Other operational constraints, characteristics and their significance have to be understood if a meaningful and practical solution is to be found for a Furniture Manufacturers 2dc problem.

A temptation in modelling such elements of complexity is to identify the data such that it fits neatly into a specific Operational Research problem type. The two dimensional cutting problem, for example, could be modelled by adopting the Gilmore and Gomory, programming approach. However, although appearing to be very efficient on the one dimensional cutting stock problems, in the two dimensional case, the programming approach leaves the following residual problems unsolved for the Planner.

- the composition of the cutting patterns;
- too many patterns to panel order inputs;
- inability to sequence the cutting patterns;
- no control over the pattern run length;

Other authors (9, 23) have also highlighted the practical difficulties of following the Gilmore and Gomory approach and have offered improved modelling approaches which have nullified, to some degree, the residual problems. [see specifically Kuuntti & Voutilainen's Euro III paper]. The majority of this published work however, has focused attention on defining the 2dc problem as a waste minimisation problem type. The objective function being to minimise the trim loss. The operational variables of:

(b) Cost of cutting;

(c) Volume throughput;

(d) Number of patterns to orders;

(e) Handling and storage problems;

(f) The spread of the order across too many cutting patterns;

being used in a negative way to simplify the actual decision problem, rather than as an aid to understand and formulate the problem.

The irony of the situation is that these operational variables are only a generalisation of the problem area, as seen from a Planning viewpoint. They are a sub-set of variables, used by the Planner to evaluate the state of play at various intervals of time, for specific goals, within the conversion operation. Decisions already taken at a higher management level, in the following areas:

(g) Saw purchase decision; linked to method of primary conversion.

(h) Machining approach; rough or finish cut.

(i) Batch size.

(j) Storage capacity between machine groups.

(k) Marketing orientation.

(l) Method of construction; D.I.Y. or assembled

have in effect bounded, in some way, the problem and hence in a mechanistic way control the possible solutions for the individual Furniture Manufacturers 2dc problem.

3.2.1 Criteria Must be Matched to Circumstances:

The positive and negative affects associated with variables (a) thru (f) ... the symptoms; are a direct/ indirect resultant from decisions previously taken by management in areas (h) thru (i) ... the primary decision areas. Unfortunately these primary decision areas receive little if any attention at the problem definition and model formulation stage. The majority of the time being spent on identifying and hence treating the symptoms rather than the causes.

An explanation of this phenomenon may be found in the fact that the majority of operational research problems are simplified so as to model the problem from a known set of problem types. There are of course many instances where such simplifications do model the problem under analysis satisfactorily. A major weakness, however, is that in following such a fixed and ri gid approach the analyst will effectively exclude from consideration, variables, issues and industrial characteristics and peculiarities, which although relevant to the problem, are difficult or impossible to model by normative modelling techniques. As Stainton (13) points out:

" .... There can be no once and for all objective which is satisfied by a ready made technique. There are objectives within objectives and thus it is necessary to look further than the immediate environment in order to identify the real problem ....."

The argument then is not that the traditional modelling approaches are incorrect, but that they too often become the framework which encourages the analyst not to think what to think about. The point for the analyst to be consciously aware of is that criteria must be matched to circumstances and not the other way around.

3.3 VARIETY REDUCTION of MEANINGFUL CRITERIA

There are considerable differences between the previously documented trim problems and the trim problem that exists in the Furniture Industry. For example, the Paper and Glass trim problems are based on a continuous flow manufacturing process, with the cutting operation and hence the trim problem appearing towards the latter stages of manufacture. Their residual problems therefore being confined to the following:

- set up costs;
- the number of cutting patterns to order inputs;
- scheduling of cutting patterns; and the
- planning horizon applicable to the product and its market.

One of the major and most significant differences between the Glass/Paper and Furniture Industries 2DCP's is that the conversion process in the manufacture of furniture is often the first operation in a long and inter-related manufacturing chain. The result is that there are a host of decision criteria, with respect to the primary decision areas, (h) thru (l) which have to be understood and taken into consideration at the problem and model formulation stage.

3.3.1 Getting Started

Certainly a start point, as advocated by Jackson, (30) and Ackoff (32), is for the analyst to understand the problem; its surroundings and the actors involved. The 2dc problem, for example, throws together a large cross section of in terested parties. From Designers; Purchasing Manager; Planner (Production Controller); Mill Manager and the Sawyer. All of course have their own set of beliefs as to what is important within the same problem. Unfortunately no vehicle is given to assist the analyst in thinking what to think about. It requires an active way of mulling things over which would allow the analyst to gain insight and an understanding of the problem and its inter-connections.

Eden, Jones and Sims (31) have argued that an important and often neglected part of tackling an ill-structured or complex issue is to gradually make aspects of the issue explicit so that a more thorough, careful and systematic analysis may be carried out. As many Operational Researchers can testify to, the most difficult part of any project is often getting started. Jackson, (32), suggests the use of an exploratory scenario to help with this initial formulation stage. In this suggested approach, the decision maker begins by letting his mind 'run loose' talking and writing down those ideas on possible strategies and outcomes. Whilst in theory this brain storming is a good start point, in practise the process of thinking out loud, of making one's thoughts clear is one which most people find difficult to do unaided.

For example, it is easy to see that the primary decisions of:

(g) Saw Purchasing Decision;

(h) Machining Approach Adopted;

(i) Batch Size:

(j) Storage capacity between machine groups;

(k) Marketing Orientation of the company;

(l) Methods of Construction;

control, to some degree, the Furniture Manufacturers cutting pattern problem. At the initial model formulation stage however, it is difficult to understand the inter-relationships of the variables and more importantly, which of the variables are the critical ones. An initial attempt in isolating single problems such as waste minimisation; volume throughput; set up time and the like, from within the total problem set and attempting to solve each of these issues independently was unsuccessful. Such an approach ignores the links between the sub-problems and therefore much of the essential characteristics of the total problem are omitted from the model base. In an effort to capture these links and to aid the thinking aloud process, help was sought from the Science and Decision Analysis Group (SDA) within the Management School, at the University of Bath. The remainder of this chapter therefore details the model formulation process of the Furniture Manufacturers trim problem.

3.4 A CONCEPTUAL MODEL OF THE FURNITURE MANUFACTURERS TRIM PROBLEM:

A series of meetings were arranged between the author and a member of the SDA (Mr T Smithin) where considerable attention was paid to 'thinking what to think about', re the 2dc problem. A significant part of these meetings were spent using a computer package called COPE, which has been developed by the OBG at Bath University. The COPE model has been designed to assist individuals and groups think around and explore their problems in a more structured way. Fundamental to this approach is the construction of a cognitive map, which is a graphical representation of an individuals, (or groups) ideas and beliefs about his particular problem and the causal links that exist between them. The cognative map is developed, over a period of time, through a process of discussion and feedback between the participant and the facilator until an adequate model of the participants problem is achieved. In the following paragraphs the basic method adopted in thinking through the issues contained within the Furniture Manufacturers trim problem is outlined.

Initially the Furniture Manufacturers 2dc problem was sub-divided into a set of sub-problem headings:

(a) Edge waste costs.

(b) Cost of cutting.

(c) Volume throughput.

(d) Panel spread.

Each sub-problem was then taken, in turn and the positive and negative characteristics of that sub-problem enumerated. ie. for (a) Edge waste costs the initial characteristics were:

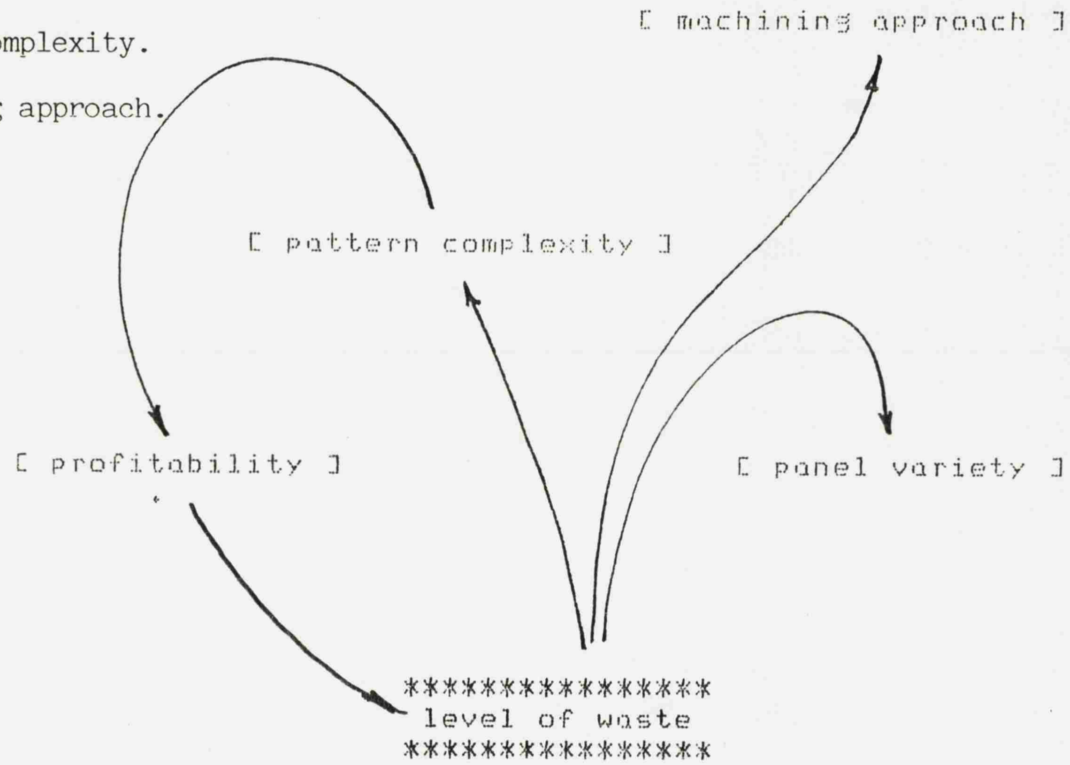
1. Level of waste.
2. Profitability.
3. Pattern complexity.
4. Panel variety.
5. Machining approach used by the Company.

The coding of these characteristics, which follows Eden, Jones and Sims (31) resulted in a simplistic cognitive map as illustrated in figure 4.0.

s simple map the characteristic of "level of waste" wn to be linked to the characteristics of:

attern complexity.

machining approach.



ition, the characteristic pc is further linked to profitability.

FIGURE 4.0 EXPLANATION OF CHARACTERISTICS THAT EFFECT WASTAGE : MAP 1

3.5 GLOBAL DESCRIPTIONS:

On analysing and discussing the sub-map about the importance of the characteristics relating to the level of wastage variable, it became obvious that in some bases these characteristics - concepts - did not directly link to the wastage variable but were global descriptions of a preferred requirement. The concept [panel variety], for example, is not directly linked to the level of wastage but is linked by a notional belief about an increase in [panel variety] leading to a potential reduction in the level of waste, all other things being equal. In addition the concept [machining approach] can be further expanded into a two level chain where the initial method of machining selected effects the processing size of the panel; eg. rough cutting at the sawing operation increases the wastage levels. These additional explanations of map 4 are shown in figure 5.0/map 2.

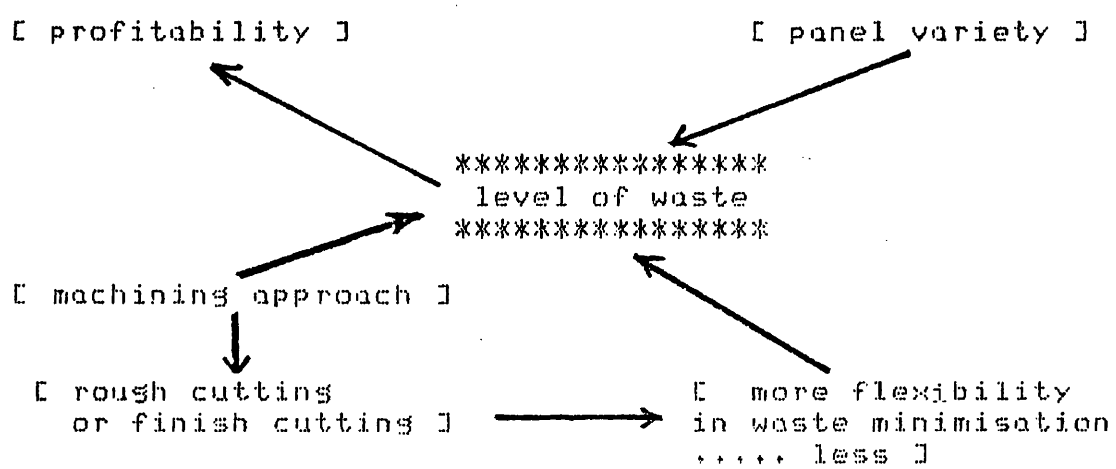


FIGURE 5.0 EXPANSION OF FIGURE 4.0/MAP 1 : MAP 2

3.5.1. Further Exploration:

A typical analysis session then would involve an initial ramble around specific issues related to the Furniture Manufacturer's trim problem.* The significant concepts and links, about the sub-problem being drawn on a blackboard or flipchart by the Facilator. This had the effect of clearing ones mind about areas of primary concern and encouraged further elaboration and exploration around these concepts which were then added to the charts. As the map of related concepts became more defined and fixed and they were then transferred to the computer via the Cope inter-active software. Exploration of the computer model*, as amended by the new sub map would reveal how the new part of ones beliefs about the problem linked to the previously created parts of the model. As the model became more complete the Cope graphics and hard copy print-outs were used to focus and link together the previously identified sub problem areas onto one map.

The completed sub-maps that describe the Furniture Manufacturers trim problem are similar in form to the detailed map, which is illustrated in figure 6.0/MAP 3.0. However, prior to detailing these sub problem maps we briefly detail, by use of a simplified worked example, the main features of cognative mapping.

* The computer model developed relates to the 'general case', rather than a specific FM.

3.5.2 Cognitive Mapping:A Worked Example

The example illustrates the implication that incorrect saw configuration may have on company profitability.

A cognitive map contains concepts linked by signed arrows. The arrows indicate that one concept; "description of event" leads to or has some effect on another concept. Eg. Selling price is linked to Sales level.

Concepts are essentially depicted as being made up of two complimentary parts. These parts "or poles" may be described directly, eg. Maximum ......Minimum, or indirectly as An increase in .... or Decrease in.

A positive arrow, 'no sign at arrow head', indicates that the first pole of a concept leads to the first pole of the other concept and that the second pole of a concept leads to the second of the other concept, Eg.

" ... an increase in unit costs
leads to
an increase in selling price ..."

A negative arrow, 'minus sign at arrow head', indicates that the first pole of a concept leads to the second pole of the other concept and vice versa. eg.

" ... an increase in selling price
leads to
a decrease in sales level ..."

With reference to these general notes on the interpretation of cognitive maps, the issues which relate to the incorrect saw configuration on profitability can be explained as follows: (see map 3)

The incorrect infeed/outfeed configuration of the sawing machine can significantly decrease the volume of boards cut and hence volume throughput is reduced. For example, if the cutting patterns, although being simple cross-cuts, are made up by more than six different panel types, the sorting and stacking operation at the outfeed operation becomes the longest time element and hence the controlling factor in the saw cycle time. The result is that volume requirements are likely to be minimised; unit costs increase.

If the unit cost increase is deducted from the profit margin then profitability must fall. Similarly, if the selling price of the product is increased there is the likelihood of a reduction in the level of sales; both negatively affect profitability.

This simplified example illustrates a typical sub-map and the causal explanations and interpretations that can be derived.

*** MAP OF INCORRECT SAW CONFIGURATION.***

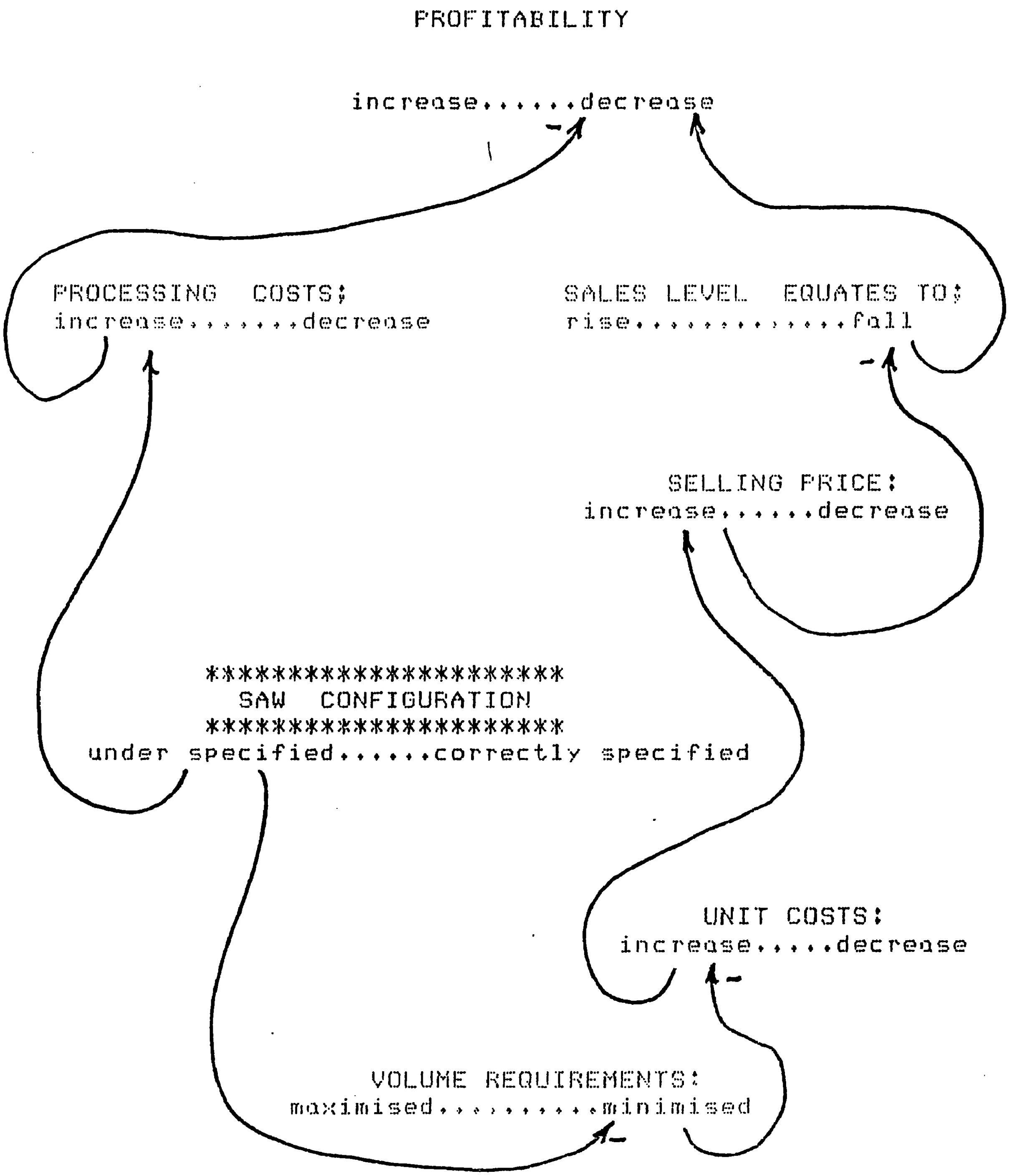


FIGURE 6.0 EXPLANATION OF INCORRECT SAW CONFIGURATION.

MAP 3.

3.6 INTERCONNECTED VARIABLES:

In addition to the output of maps. the COPE programme also provides the User with numerous analytical features, ie. ability to trace feedback loops; the facility to look for conflicting explanations and consequences. This latter facility proved to be a great help in thinking through and sorting out the many inter-related and intertwined issues that were contained within the Furniture Manufacturers 2DC problem.

By using the grouping and hierarcial analysis procedures, contained within the COPE software, it is also possible to identify and analyse in detail areas of the map that exhibited high levels of activity. ie. concepts that have high linkages. Not surprisingly after much detailed analysis it became quite clear that the major interconnected variables that are required to be considered and understood when generating cutting patterns were as follows:

(a) VOLUME THROUGHPUT

(b) PROFITABILITY

(c) WASTE LEVELS

(d) SAW DESIGN : PRIMARY CONVERSION METHODS

(e) PATTERN COMPLEXITY

The sub maps relating to the Volume and Profitability variables are now detailed.

3.6.1 **** MAP OF VOLUME THROUGHPUT ****

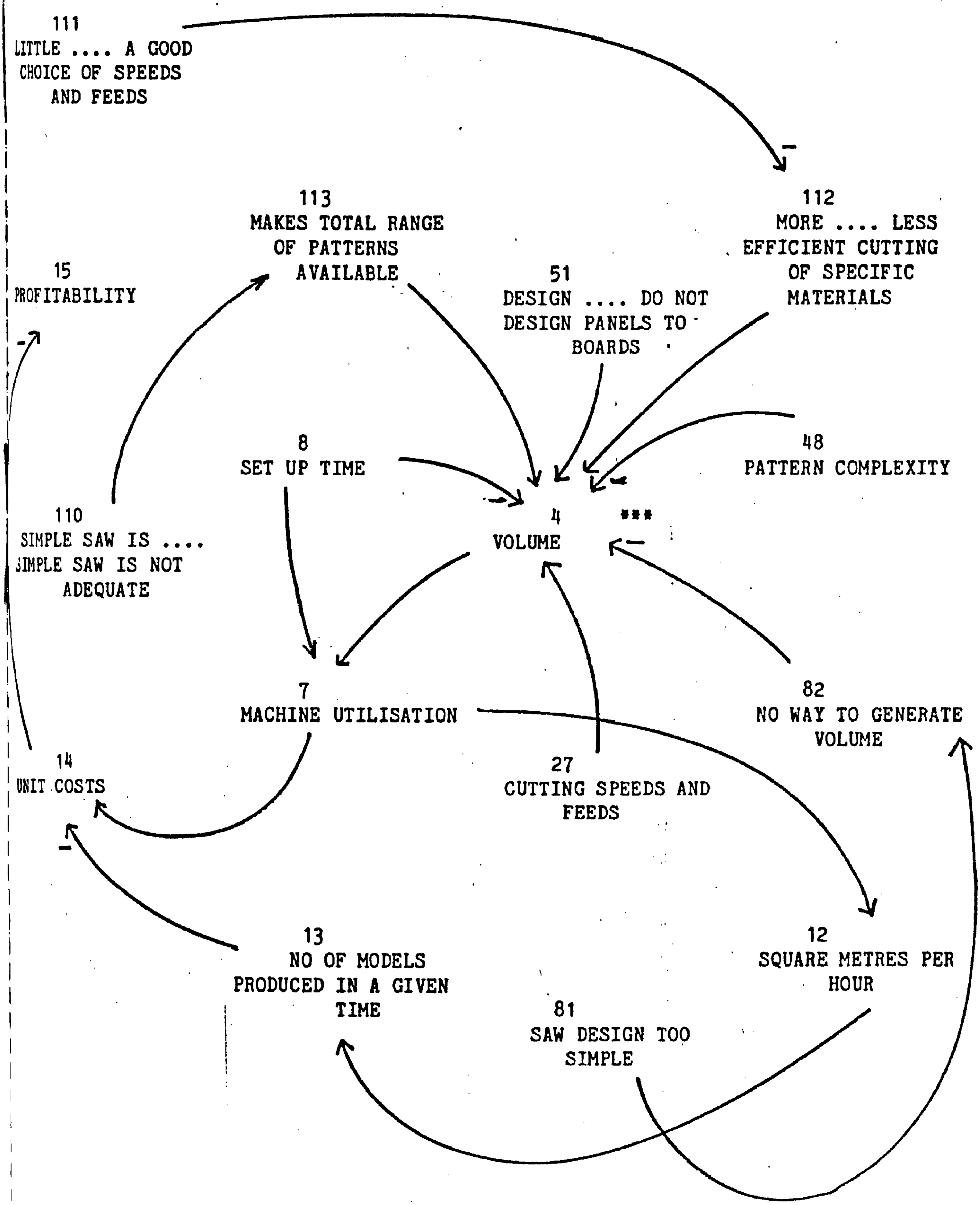


FIGURE 7.0 MAP OF VOLUME THROUGHPUT: MAP 4

3.6.2 Analysis of Map 4 : Volume Throughput:

The major variables*which negatively effect volume throughput are:

1. [pattern complexity] : As the complexity of the cutting pattern increases the more time is required at the cutting operation and hence volume throughput is reduced. It should be noted that pattern complexity is not a linear function. Volume throughput can be significantly affected by the level of pattern complexity of the cutting pattern, which in turn is controlled by the design characteristics of the sawing machine.

2. [saw design] : Each sawing machine has a theoretical maximum volume output per hour. This output value is a function of the design characteristics of the saw. If the saw is too simple - ie. cross cut saw is too small; manual rather than mechanical infeed/outfeed or has no electronic setting - then the ability to achieve the stated volume output depends largely on non-machine dependent variables and as such the actual, practical volume throughput will be significantly reduced. This is shown in map 4. by three linked routes, namely:

* These definitions are based on empirical findings, which have been substantiated by practical test results.

V100 // V111 // V112 // V4 volume

V110 // V113 / V4 volume

V8 // V7 // V12 // V13 // V14 // profit;

Linked to

These explanations, given in map 4, go some way to indicating the operational variables which relate to and hence control the volume throughput at the sawing operation.

In practise we have found that the volume variable is not directly used as a performance indicator by any of the interested parties. For example, the Sawyer tends to use number of boards/square metres per hour : the Planner, machine utilisation and or number of models required with the Production Manager tending to concentrate on the current unit costs. all of these personalised measures of performance leading to the profitability variable. As the following sub map illustrates, the profitability variable is intertwined across many managerial operational decision areas.

3.6.3. **** MAP OF PROFITABILITY ****

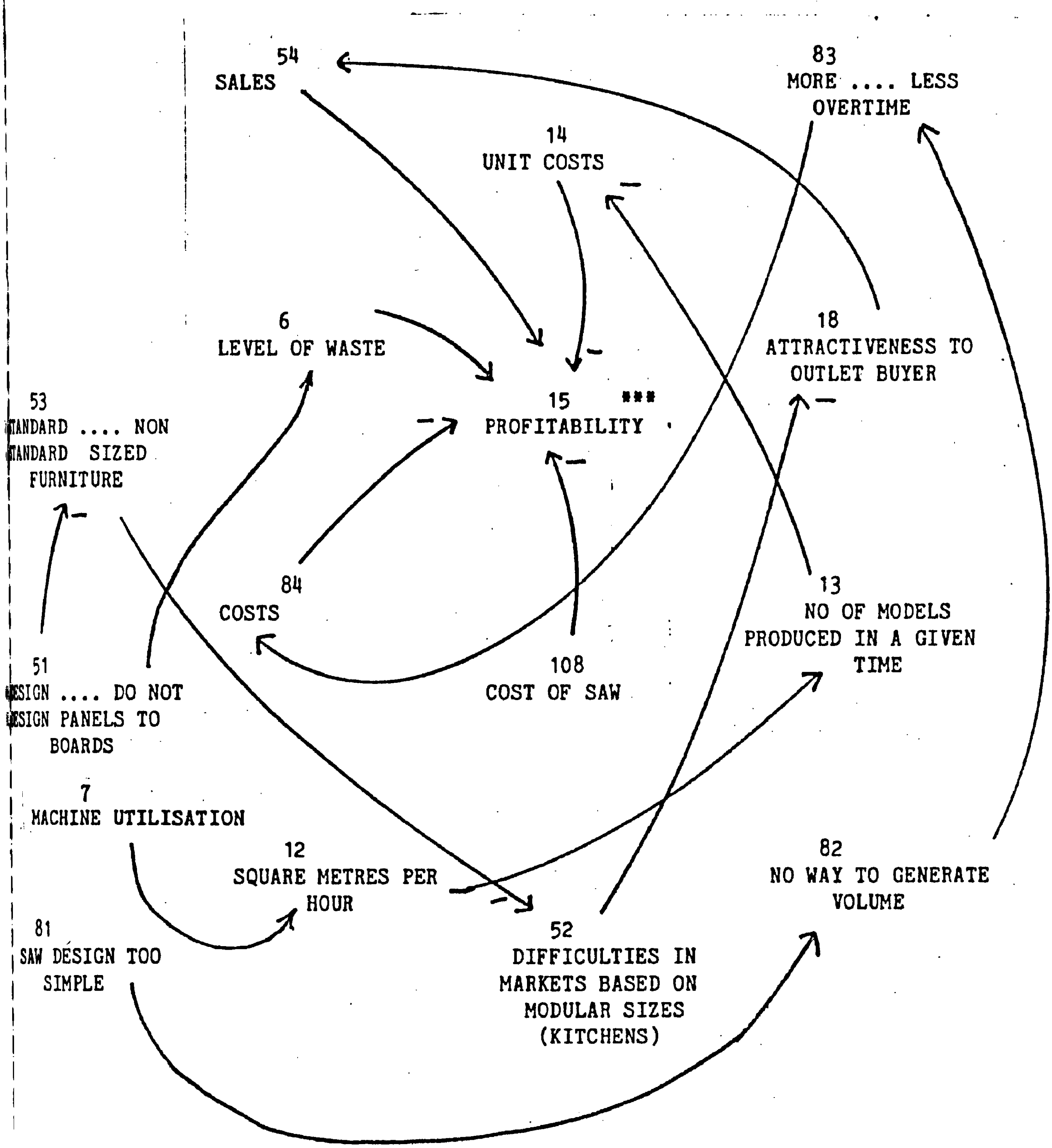


FIGURE 8.0 MAP OF PROFITABILITY:
MAP 5.

3.6.4 Analysis of Map 5 : Profitability:

Variables which negatively effect the profitability variable are:

1. [design ... do not design panel sizes to board sizes]

Clearly if at the design stage the size of the panels were directly factored into board sizes, then trim loss would not be a problem. Unfortunately such a simple solution is not possible due to the following:

(a) Furniture sizes are related to their respective end usage. For example, although it would be cost effective to reduce the depth of a wardrobe from its customary 560 mm to 500 mm, which would enable four to be cut from a board width of 2050 mm, the 560 mm dimension is required to match the nominal width of the coat hanger. In addition, some markets are based entirely on modular sizes. eg. kitchens. In these circumstances the Furniture Manufacturer is constrained on the dimensions of the panel sizes.

(b) Although designed to be functional, furniture has also to be attractive to the Outlet Buyer. Thus although it would be possible to design a furniture model so that little waste resulted, the attractiveness of the model to the Outlet Buyer would probably be zero. The phrase "attractiveness to the Outlet Buyer" then is critical for that specific product and the overall profitability of the company. In practise we have found that the design of furniture is more likely to be orientated towards satisfying a particular Output Buyer and his price-pointing policy than towards the economic use of materials and labour. An example of this can be found in the use of shaped ends on lounge units which cause difficulties in material utilisation and in machining.

Whilst there are many other implications that can be derived from these sub maps, it becomes clear that the Furniture Manufacturers trim problem is not totally related to waste minimisation alone. In practise the Furniture Manufacturers two dimensional cutting problem encompasses a complex, inter-related set of problem issues as illustrated in figure 9.0 map 6. This requires the Planner to consider wastage and other consequences, when generating cutting patterns. These other consequences include:

- cost of cutting; related to pattern complexity;
- volume cut per hour;
- ratio of cutting patterns to panel orders;
- the spread of the panel order across the cutting pattern set;
- handling and sorting issues at the outfeed table of the sawing machine;

The main objective of the Planner, in cutting pattern generation, is to generate cutting patterns which satisfactorily take account of these consequences and other industrial characteristics, whilst maintaining a bālance between them all, rather than optimising one objective at the expense of the remainder.

3.6.5 *** MAP OF 2DCP MAJOR VARIABLES: ***

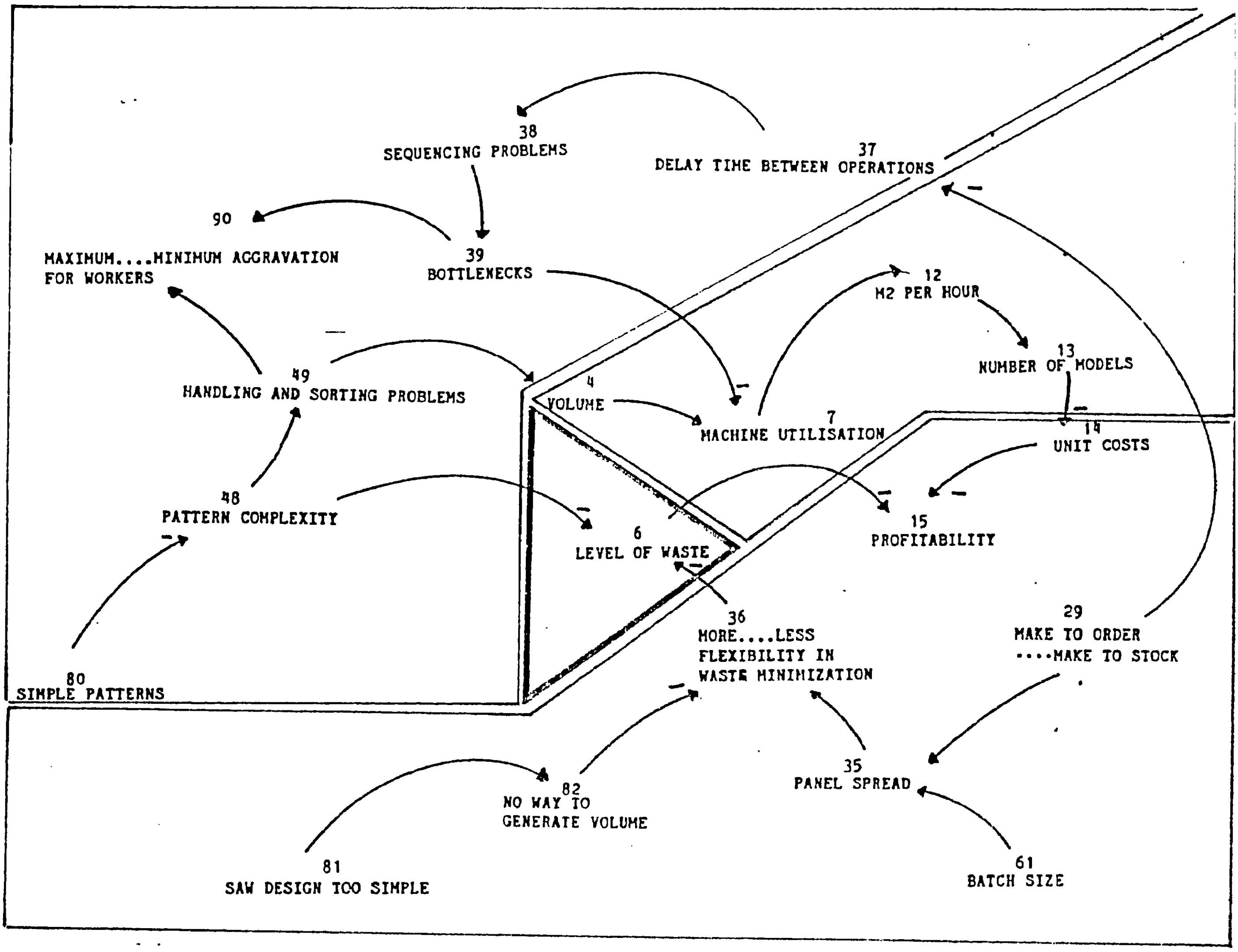


FIGURE 9.0 MAP OF THE MJAOR VARIABLES THAT THE PLANNER
MAP 6 CONSIDERS WHEN GENERATING CUTTING PATTERNS

3.6.6 ANALYSIS OF MAP 6 : INTER-RELATED VARIABLES:

Map 6, clearly indicates the inter-related nature of the problem that the Planner faces in generating cutting patterns. In general terms there are three main variables that the Planner is required to balance, namely, waste; volume and machine utilisation. Each of these variables are variously inter-linked and obviously have some effect on one another. For example, the concept [pattern complexity] directly affects the level of waste but is controlled to a large degree by the saw design; this in turn cascades through to the overall profitability objective; the level of pattern complexity also links to handling and sorting issues which is further linked to the volume variable.

The majority of the published papers to date have tended to concentrate purely on the mathematical solution component of the cutting stock problem rather than the technology component. The latter component only being considered with reference to order tolerances and knife changes. The result being that the computerised cutting patterns so produced were often not feasible. As sub maps 4, 5 and 6 indicate, the Furniture Manufacturers 2dc problem is not just a simplistic waste minimisation problem. Other industrial p. ecularities and characteristics have also to be considered, understood and incorporated into the model, at the problem formulation stage, if a meaningful and more robust solution is to be derived. In Chapter Four, these significant variables detailed in this Chapter will be further expanded.

3.7 SUMMARY

Prior to using the facilities offered by the research group, at the University of Bath, it had always been difficult to get to grips with many aspects of the 2dc problem. It was not that the problem could not be verbalised, it could. However, the complex, inter-relationship of areas from Design, Purchasing, Marketing, Manufacturing and Operational Management resulted in an impossible tangle, which was required to be thought through and understood before one could realistically start the problem formulation stage.

The phrase "problem formulation" is slightly mis-leading in as much as it suggests a definitive staged approach where the problem under analysis is identified, simplified, modelled and solved. This structured approach to problem formulation, although suitable in many instances is not helpful at the initial stage of thinking through and sorting out the significant issues contained within the overall problem. This is especially so when there is not one clear concise, easily definable problem. Given such circumstances, the requirement is for a vehicle that will aid and assist the model builder in understanding the many issues that surround and go to make up the problem. Whilst far from ideal, the cognitive map approach, followed in this research, provided that vehicle. As our recent paper on the topic of the 2dc problem indicates, the ability to dump out and structure ones belief base, about a problem and to be able to interact with and explore those beliefs, as the model of the problem is developed, only increases one's understanding of the nature of the real problem. (35).

3.7.1 Cognitive Mapping as a Modelling Technique: Comments:

The first point to note is that the activity of modelling by definition equates to a simplification and reduction of the data that goes to describe the actual problem under analysis. In addition and a point often overlooked, is that the deliberate process of model building will affect - even change, perhaps - the problem that is being studied. Irrespective of whatever the modelling approach adopted then, these two points will hold.

The decision to use the cognitive mapping approach, as a modelling technique, was based upon the fact that we were unable to think of all the possible consequences of explanations that went to make up the 2dc problem and hence required a modelling technique that aided and assisted the thinking process. It is against this background requirement then that we make the following remarks on the experiences gained from using the technique of cognitive mapping.

(a) The cognitive mapping approach allowed a valid construction of the issues and beliefs which surround the 2dc problem to be depicted but more importantly allowed me to question and explore the detail characteristics within the problem.

(b) The resultant model - The Furniture Industry model - provided the vehicle which facilitated a dialogue between me and my own knowledge base. This significantly aided the thinking process, in as much that I was able to handle levels of complexity which previously I had been unable to handle.

(c) A disappointing experience was that there were no real surprises in the cognitive maps relating to the 2dc problem. This in retrospect is perhaps correct, given that the coding and structuring of my beliefs about the problem were carried out carefully and correctly and as such the maps of reality were already sketched in, in my own sub-conscious.

Although no serious limitations were encountered in my direct usage of the cognitive mapping modelling approach, the following points were irksome. in as much as they limited further detailed analysis, especially in the quantitive area, on the relationship of the significant variables of waste; volume; panel spread and the pattern to panel order ratio.

(d) It is not possible to describe beliefs about causality in anything other than monotonic relationships. eg:

The strengths of the various concepts/attributes cannot be coded: ie. the relationship between the conflicting goals need not necessarily be of a 1 to 1 relationship, or be compared by the same unit of measurement. For example, cutting patterns are often judged by the resultant level of waste, rather than any other criterion, as this is the easiest attribute to measure. However, in trying to minimize the spread of an order across too many cutting patterns, the Planner is required to intuitively trade off wastage verses panel spread. Rarely will both of these attributes have a 1 to 1 relationship, neither is it likely that their respective units of measurement will be the same. Therefore, although cognitive maps identify the relationship between the concepts, the ability to tangibly reflect the degree and level of importance of one concept to another, in hierarchical fashion is not possible.

This limitation however has to be viewed against the background that cognitive mapping as a modelling technique is to do with expressing beliefs about a problem as opposed to being a predictive model.

(e) Coding demands a certain clarity of understanding of what the problem is and the ability to verbalise the concepts related to that problem in a few words, often with brief alternatives indicating the positive and negative sides of the concept. Not all potential cognitive map Users will have these verbal strengths and hence the almost clinical precise verbal reduction ability may well serve as a barrier against the techniques wider usage.

(f) The major benefit in using the cognitive mapping approach was the freedom of not having to hold everything in ones head about the problem. This combined with being able to concentrate totally on one specific area at a time, knowing that the implications to other areas would be recorded by the software, enabled a much more detailed model about what was important, to be formulated, than would otherwise have been the case, and it is with this significant background knowledge about the technology components contained in the Furniture Manufacturers 2DC problem and how they relate to one another that we proceed to carry out a detailed evaluation of those major technology components in the following chapter.

CHAPTER FOUR : DETAILED EVALUATION OF THE TECHNOLOGY COMPONENTS OF THE 2DC PROBLEM

4.0 PRIMARY VARIABLES

As mentioned by Jackson (12) one possible explanation for the poor record of implementation within Operations Research, vis-a-vis the 2dc problem is that often the initial emphasis is given to problem solving rather than to problem understanding and formulation. For example, at this point in the research a solution strategy could be offered to the Furniture Manufacturers 2dc problem. That strategy would however be based on the solution approaches identified and recorded in the literature, ie. neat linear and dynamic programmes and/or ingenious heuristics. Although these suggested methods might very well provide an optimal solution to the model of the cutting problem so constructed, such optimality would be optimal with reference to the model and not the actual problem. The reason for this is that the importance or otherwise of the technology components that go to make up the cutting problem are not understood in any depth. In reality the cutting problem has only been drawn in outline - the awareness stage. In this Chapter therefore the primary technology variables, previously identified in Chapter Three are further detailed and evaluated. The objective of the evaluation is twofold:

firstly to understand the influence that the technology components have on model definition. And secondly, to define a robust model base which combines the mathematical and technology components.

The selection of the following primary variables was determined by utilising the part of the Cope software package which identified the variables with the highest activity. ie. highest number of input/output relationships. The result of the analysis being as follows:

Primary Technology Variables:

1. SAW DESIGN and METHODS OF PRIMARY CONVERSION.
2. LEVELS and COST OF WASTE MATERIAL.
3. COST OF CUTTING and VOLUME THROUGHPUT.
4. PATTERN DISCONTINUITIES.

and it is these primary variables which are now further expanded and evaluated.

4.1 SAW DESIGN AND METHODS OF PRIMARY CONVERSION

The primary conversion operation; the cutting of boards into panels can be achieved by utilising two different sawing approaches, namely:

(a) The Traditional Approach

(b) The Systemised Approach

4.1.1 The Traditional Approach:

There are two basic design concepts that are fundamental to this method of primary conversion.

(i) The primary conversion operation is treated as two or three separate machining operations. ie. operation No. 1 is length cutting - operation No. 2 is cross cutting and operation No. 3 is Z cutting.

(ii) The material to be cut has to be pushed against a series of static saw heads, which are mounted on the front and rear saw beams, ie. the material moves rather than the saw heads, which remain static. This saw design concept constrains boards to be cut one at a time, rather than in multiples.

In general there are a group of two or three such saws, dependent upon the volume requirement. Their layout, which is diagramatically shown in Figure 10, being such that one saw - the length cutting saw - breaks down the board material into length strips of varying widths. These length strips, from the first cutting operation, are handled and / or conveyored directly to the second and third sawing machines, or go to a strip storage area, to await further processing.

The object of the second cutting operation is to cut across the length strips thereby effecting sized panels. If however, this cross cutting operation does not size the panel then a third cutting operation is required. This third stage, or Z cutting operation, can be achieved by the following three machining alternatives:

(a) A second pass through the same saw: This is only considered when the volume to be cut is high as small run quantities result in greater setting than run times.

(b) By using a smaller sawing machine, away or off-line from the main saw: These smaller machines require less setting time than the large machines and hence when smaller volumes are required, they are preferred.

(c) When the size difference between the sawn panel and the finish size requirement is less than equal to 15-20 mm, and there is sufficient order quantities, then panel sizing can often take place at the tennoning stage of manufacture, ie. the majority of panels pass through the tennoning operation and hence given enough volume this Z cut sizing can be easily achieved at the tennoning stage of manufacture.

1.2.2 Constraints for the Traditional Approach to Sawing:

1. The number of strips is governed by the total

number of saw motors or heads which are mounted on the front and rear saw beams. [nominally each saw has eight saw heads].

2. The throat size of the machine effectively constrains both the maximum board size and the orientation of the first pass through the saw. ie. if the board length is greater than the throat width then it is not possible to cut across the board width first.

3. In practise, only one pass through saw A - the length cutting machine - is permitted.

4. Due to the difficulties experienced when handling the large board sizes and the limited space in and around the working areas, there is a high cost associated with every change of board size. For example, each board or pattern change typically results in the loss of 0.3 hours x 2 (the number of saw operatives) and for each saw head change the time required is 0.10 hour per saw head.

5. Boards are cut in singles only, hence there is a tendency to produce low volume output unless the saw group is planned for as a group and the number of board and pattern changes are kept to a minimum.

A typical saw layout for the Traditional approach is given in figure 10.0.

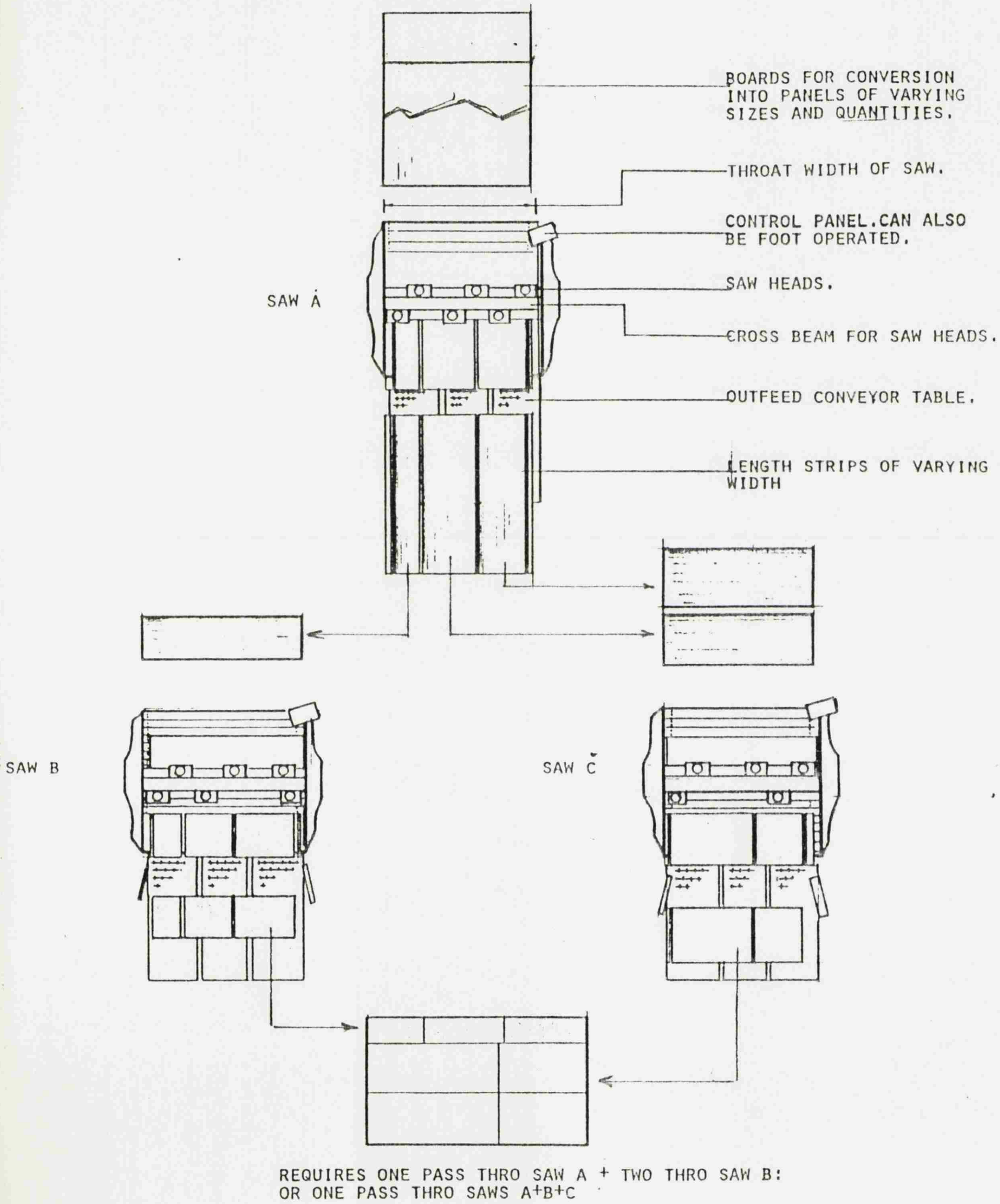


FIGURE 10.0 TYPICAL SAW LAYOUT FOR TRADITIONAL APPROACH

4.1.3 THE SYSTEMISED APPROACH TO PRIMARY CONVERSION

Traditionally then the saw cutting machines were constructed on the concept that the material was cut singularly and had to be pushed against the saw blade. The result of this approach being that the panels so cut were neither square nor dimensionally accurate. The main reason for this inaccuracy being due to the release of the residual stress inherent within the large chipboard sheets when cutting takes place with the boards unclamped.

As the general acceptance and hence usage of chipboard meterials increased, a different approach, which resolved the dimensional inaccuracy problem of the Traditional primary conversion method was required. This necessity lead to the development of the Systemised Approach to sawing which encapsulated the following design features:

(1) Boards could be cut in multiples.

(2) To achieve a panel which was both dimensionally accurate and square the boards were aligned and clamped to the table and the saw moved.

(3) To overcome the problem of residual stress, which are released during the cutting operation, a pressure beam, side dressing and aligning after each cutting stage was introduced.

4.1.4 The Angular System Approach to Primary Conversion

In addition to these technical innovations, the idea, generally acknowledged to have emanated from Giben of Italy, early in 1950 of linking, at right angles, two panel saws, each having one cutting line, was developed to meet the demand for mass production, as shown in figure 11.0. In this angular system approach the primary conversion operation is treated as a continuous flow sequence with no intermediate storage between the two cutting lines.

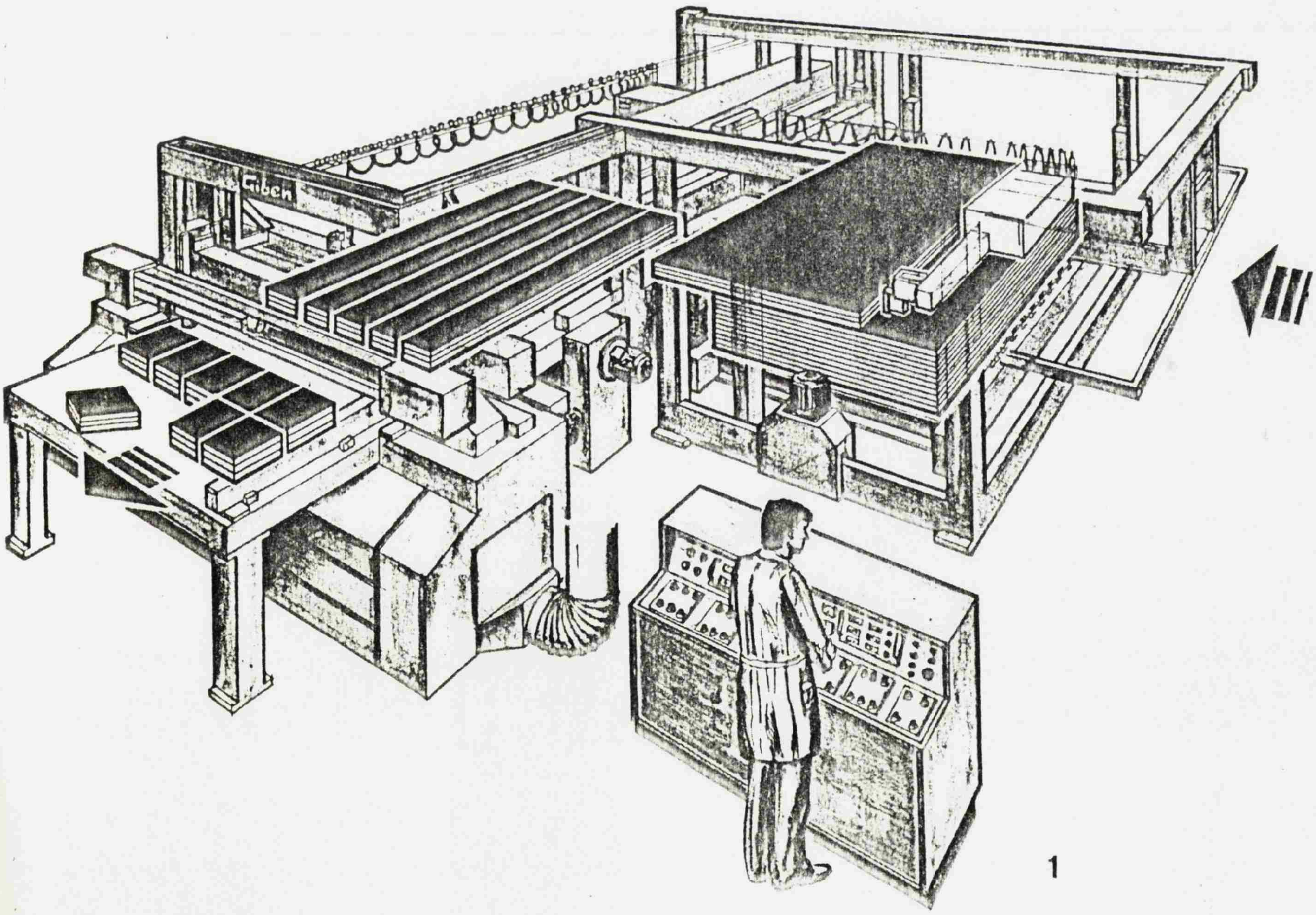


FIGURE 11.0 SCHEMATIC REPRESENTATION OF ANGULAR SYSTEM CONCEPT

4.1.5 Detailed Evaluation of the Angular System

Given that a large majority of Furniture Manufacturing companies use the Angular System approach as their method of primary conversion, detailed research of this method of sawing was undertaken. Basically there are two types of Angular Systems, namely

(a) Cutting in Sequence;

(b) Simultaneous Cutting; both these approaches are now detailed:

4.1.6 Cutting In Sequence

The basic operational elements of the cutting in sequence approach are;

1. Complete in-feed and alignment of boards, prior to length cutting.

2. Once the automatic length cutting cycle has commenced the boards, B are pushed to the length cutting line by some increment W. A pressure beam is now activated and a length cut then takes place. The pressure beam is lifted and the remaining board width is pushed by some increment W. This pushing of the board has the effect that the previous cut length strip is automatically cleared from the length cutting line. The pressure beam decends and clamps the boards. The second length cut then takes place. The length cycle continues in this manner until completed.

The result of this length cutting cycle is that the board width has been sub-divided into a number of length strips (which are equal to the board length) of width W.

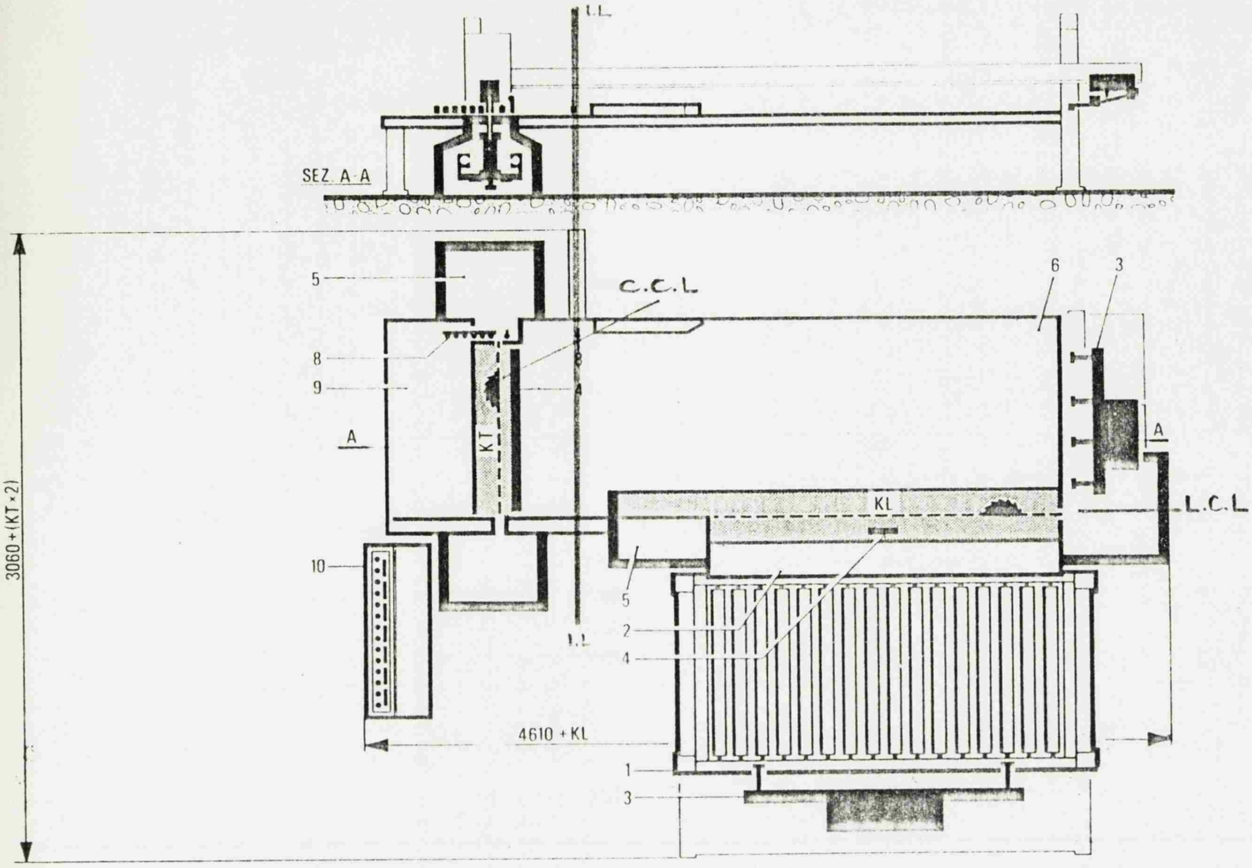
Different strip widths, W1,W2,W3....Wn can be obtained by setting the saws programmable control units. Thus the type of programme control units that the sawing machine has, effectively constrains the number of different strip widths that can be included on a single cutting pattern.

3. Next, the length strip pusher is required to push the previously cut length strips to the cross cutting line. (CCL) and after alignment, push them through the CCL by some increment of L.

The length cutting line (LCL) is now impeded until the length strips being cut on the CCL have cleared the cutting line of the length machine. (shown as IL in Figure 12.0).

The cross-cutting operation is similar to the length cutting cycle and as such is not detailed here. After completion of the m number of cross-cut cycles the length strips are cut into N panels of length PL and of width PW.

4. The length stroke pusher now returns to position A and the length cutting cycle, as described above in [2] is able to start again.



1 Electrical-mechanical lift table.
2 Connecting table; links cutting machine with lift tab 10
3 Length and cross pushers.
4 Aligning devices before cutting takes place.
5 Saw housings; saw motor and saw assembly.
6 Connecting table between sawing lines.
7 Transfer beam which pushes the length strips to the cross pusher (3).
8 Additional alignment devices used during and after cross cutting.
9 Outfeed table for sized panels.
10 Programme control panel.

KL Length cutting line
KC Cross cutting line

FIGURE 12.0 ANGULAR SYSTEM: CUTTING IN SEQUENCE

4.1.7 Simultaneous Cutting:

The basic operational elements of the simultaneous cutting operation are:

1. In the simultaneous cutting operation, as shown in figure 13, the two cutting lines, L,CL, and C.CL work together after the first initial cutting cycle through both cutting lines.

2. Waiting time between the two sawing lines is minimised since the length strips are immediately transferred, after the length cutting operation, to an intermediate station which has an independant set of pushers that are only used by the cross cutting line. (Item 3 in figure 13).

3. This then permits the length stroke pusher (7) to return to position P1, leaving the length cross cutting line free to operate. ie. both cutting lines are working simultaneously.

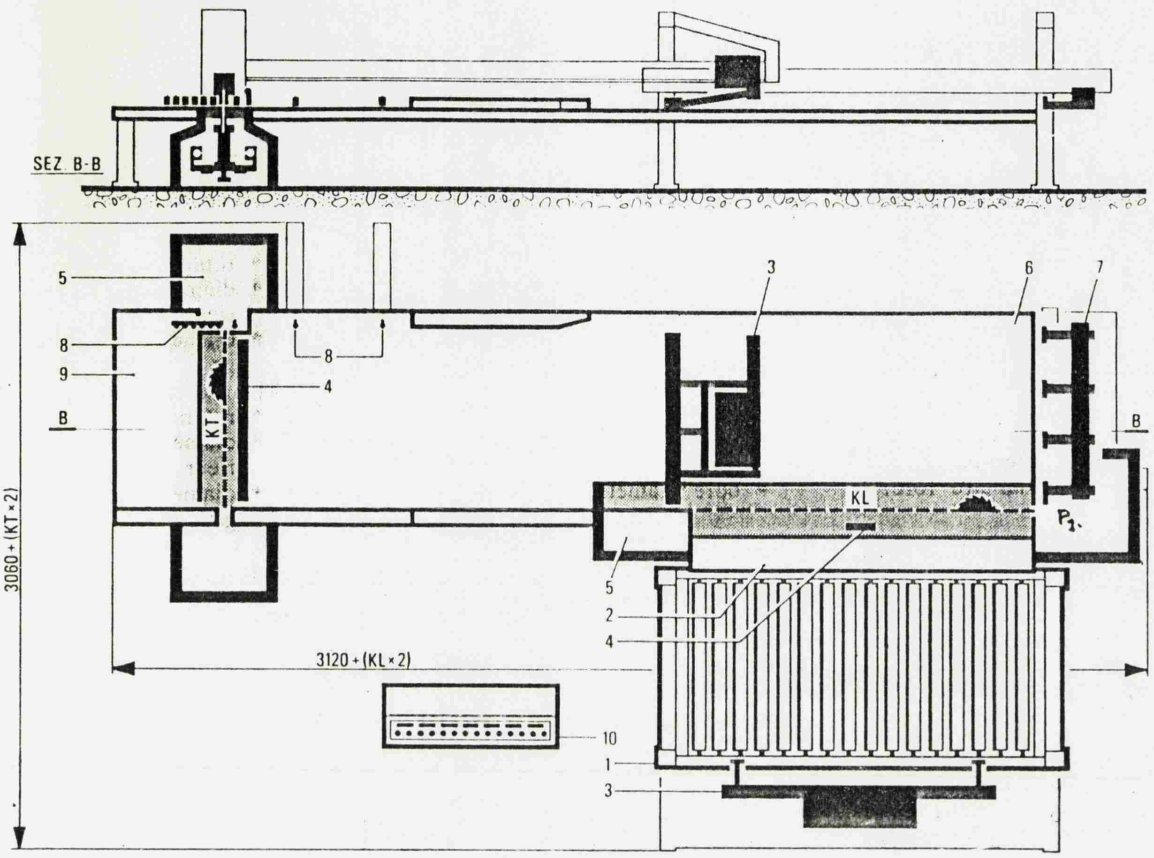
4. It would be incorrect to suggest that in the simultaneous mode no waiting time occurs between the two cutting lines. Waiting time will exist due to the fact that board lengths are larger than board widths, therefore the cross pusher has more work to complete; this is certainly the case in patterns with multi-staggers. In such circumstances the length cutting line is required to wait until the cross

pusher has effectively cleared the length cutting machine line, see 1L in Figure 13.0.

This queue problem of ripped length strips waiting at the cross cutting line can be minimised - and therefore volume throughput increased, assuming no grain direction - by positioning the panel length next to the board length when determining cutting patterns. By adopting such a decision criterion when generating cutting patterns, it is likely that there will be a reduction in both cross cutting and hence cross pusher times due to less cross cutting requirements. This in turn has the effect that the time for both the length and cross cutting cycles will be better balanced and hence the length cutting line will not be waiting on the cross cutting line.

5. This cycle time balancing act, which tends to restrict the possible pattern combinations, not surprisingly has an adverse effect on the wastage level. Thus one of the major requirements when using any of the Angular System Approaches to the primary conversion operation, is to understand the implication that pattern complexity levels have on the volume throughput..

In general, typical cutting pattern complexity levels for Angular systems are orientated towards the more simple cross cuts and single and multiple staggered cutting patterns.



1 Electrical-mechanical lift table.
2 Connecting table; links cutting machine with lift tab 10
3 Length and cross pushers.
4 Aligning devices before cutting takes place.
5 Saw housings; saw motor and saw assembly.
6 Connecting table between sawing lines.
7 Transfer beam which pushes the length strips to the cross pusher (3)
8 Additional alignment devices used during and after cross cutting
9 Outfeed table for sized panels.
10 Programme control panel.

KL Length cutting line
KC Cross cutting line

FIGURE 13.0 SIMULTANEOUS CUTTING : ANGULAR SYSTEM

4.1.8 Alternative Approaches to Primary Conversion

The main advantage put forward by the Angular system lobby was that the panel could be cut directly to size and as such no further or additional dimensional sizing operation on the panel was required. As the design of furniture continually moved towards total board substrates and no solids even the lippings were removed - there were rapid improvements in the area of machinery design. For example, the development of panel double end-tennons, which in addition to grooving could also dimensionally size the panel became common place in the early seventies. These tennoning machines were later linked to edge banding machines thereby forming a flow production line for panel processing.

These developments in the material and machinery areas result in the Furniture Manufacturer having, for the first time, a set of alternative primary conversion approaches available, namely:

(a) Finish cut to size panel on the saw and process on edge banding lines.

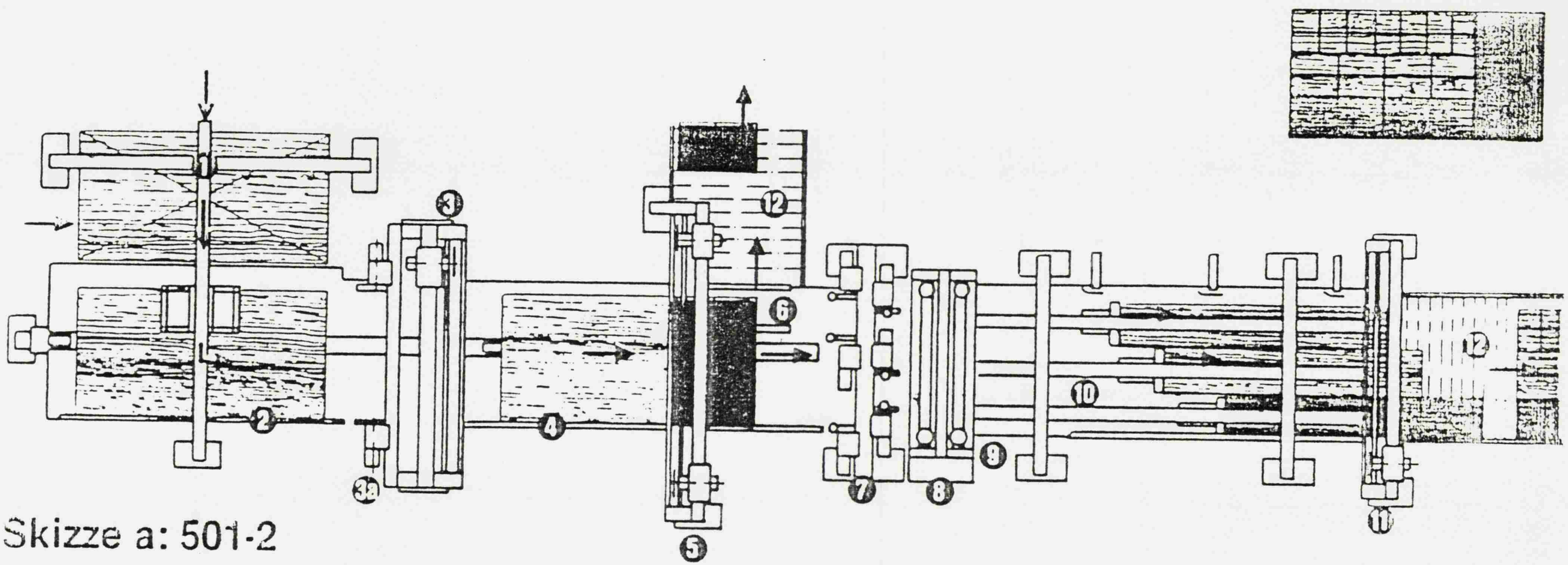
(b) Rough cut to size panel on the saw and process on linked tennoning and edge banding process line

Given that the majority of the total panel volume throughput is processed on the tennoning machines at some stage in the manufacturing process then it would appear that the second alternative would have been preferred. In many cases, however, this was not so. The major problem with the rough cutting to size sawing approach still remained that the Traditional sawing approach could not handle the high volume so often required. This volume limitation was overcome by the introduction, initially by Meyer Schwabedissen and latterly by Papenmeier of the Straight-through, high volume sawing system approach and for completeness we briefly detail the Papenmeier system.

4.1.9 The Straight Through Approach

In the Straight-through system approach adopted by Papenmeier, only one saw line is used. The saw head is mounted on a movable bridge construction which straddles the work table, The bridge (saw head) movement is therefore constrained to be in a straight line, hence its name. In contrast to other Straight through sawing systems the Papenmeier sawing head is able to rotate through 270 ang degree. This novel and very practical design eliminates the necessity for the saw head to return to a specific side to begin the cutting cycle.

As in the Angular system approach, the conversion process is treated as a continuous operation. A typical layout of a Straight through sawing system is shown in Figure 14.0.



Skizze a: 501-2

FIGURE 14.0 STRAIGHT THROUGH SAWING APPROACH TO PRIMARY CONVERSION.

4.1.10 Straight Through Approach

The basic operational elements of the Straight Through approach to primary conversion are:

1. Complete infeed and alignment of boards to zero datum position prior to length cutting operation. Alignment fence retraction and end clamps activated.

2. Length cutting operation; The saw head moves to the correct width position from datum side. Length cutting operation takes place. Upon completion the saw head clears the board edge and rotates thru 180 ang degrees. ie. the saw blade is now in the correct rotational position for cutting. During this rotational operation the saw head is constantly moving to the next width dimension. Next length cutting operation takes place. Repeat for all length cuts.

3. Cross-cutting operation: The saw head moves to the correct length position from the datum edge. Repeat as [2] but note that the bridge actually moves to the next cross cut position rather than the saw head.

4. Upon completion of the length and cross cutting cycles the clamps are released and the table belts are raised thereby elevating the cut boards clear of the work table. The belts then convey the cut panels through

the bridge and on to the take away conveyor.

5. The panels are manually taken off and stacked on to the outfeed conveyor system or to waiting stillages.

4.1.11 Implications for Pattern Generation

The Traditional Approach

In adopting the Traditional approach to sawing the Planner is assisted as the 2dc problem can be broken down into two single dimensional trim problems. Given such circumstances the only variable actively being considered is the amount of edge waste within the strip. Often the true cost of cutting is hidden by the fact that an army of people are engaged on a controlled, never-the-less ad hoc basis in Z or Off line cutting. The argu ment is not that the waste levels are low, by using the Traditional approach, rather the balancing between the cost variables associated with the total cutting operation, which would identify the real minimum total conversion cost is rarely achieved.

The Saw System Approaches

In the System approaches to sawing the Planner is forced to understand the total system. There is no possibility to effect changes in between the length and cross-cutitng operation as is the case with the Traditional sawing approach. The requirement is to conceptually view the conversion operation as a continuous flow process which cannot be interupted. In cutting pattern generation the following technology components, for the different approaches to sawing, must be fully understood by the Planner:

Angular System:

* the queue problem of balancing length and cross cutting;

* the significant reduction in volume throughput when the cutting patterns are above the double stagger level.

* the difficulty to perform head cuts.

Straight through System:

* The work table split dimensions restricts the position of the width strips on the board, with the result that not all width combinations on a cutting pattern are practical;

* panels less than 400mm in width must be positioned in the centre of the cutting pattern. This is to prevent skewing of the smaller panels during the off-loading part of the cycle;

In conclusion then these different approaches that can be adopted to the primary conversion operation indicate that it is essential that the model builder is able to identify and differentiate not only the different sawing methods and their respective characteristics but also how different Planners utilise these technology variables to simplify and in some cases structure their pattern generation problem. In addition, Furniture Manufacturers must also appreciate that in many cases their current cutting pattern solutions are bound to a large extent by their primary decision re the saw machine purchase decision.

4.2 LEVELS and COST OF WASTE MATERIAL

Edge waste occurs at two basic points within the furniture manufacturing cycle, namely:

(a) Within the manufacturing cycle of chipboard production.

(b) At the primary conversion operation in the manufacturing cycle of furniture;

these two areas are now detailed.

4.2.1 Edge Waste within the Chipboard Manufacturing Cycle

As can be seen by reference to Figure 15.0 the chipboard manufacturing cycle is a total flow process system and has many similarities to the Paper and Glass industries. For example, the cost of waste, resulting in the main from off-cuts and damaged boards is given little priority on managements cost control agenda. The main reason for this being that the wastage created within the system is automatically collated and re-introduced at the wood chipping operation stage of manufacture. In theory then no waste material ever occurs. This rather simplistic treatment of the cost of waste material also appears in the Paper and Glass industries to a large extent. ie. any paper waste is re-introduced at the pulping stage of manufacture and defective glass panels are broken down (cuttled) for re-processing in the Glass industries case.

Whilst the chipboard manufacturers were contented to manufacture pure chipboard, ie. chipboard with no surface finishing, then it was always possible to re-introduce the waste material into the manufacturing process, ie. a no waste problem situation. This contentment with being only chipboard manufacturers however, changed when it became possible, in the early seventies, to apply thin papers and P.V.C. foils to chipboard. The capital cost for such equipment was so small and the rise in the finished board product cost so great that almost all chipboard mills invested in vertical integration. Once the foil or laminate is applied however, the ability to re-introduce waste material into the front end of the manufacturing system is lost. The reason for this is that the oil

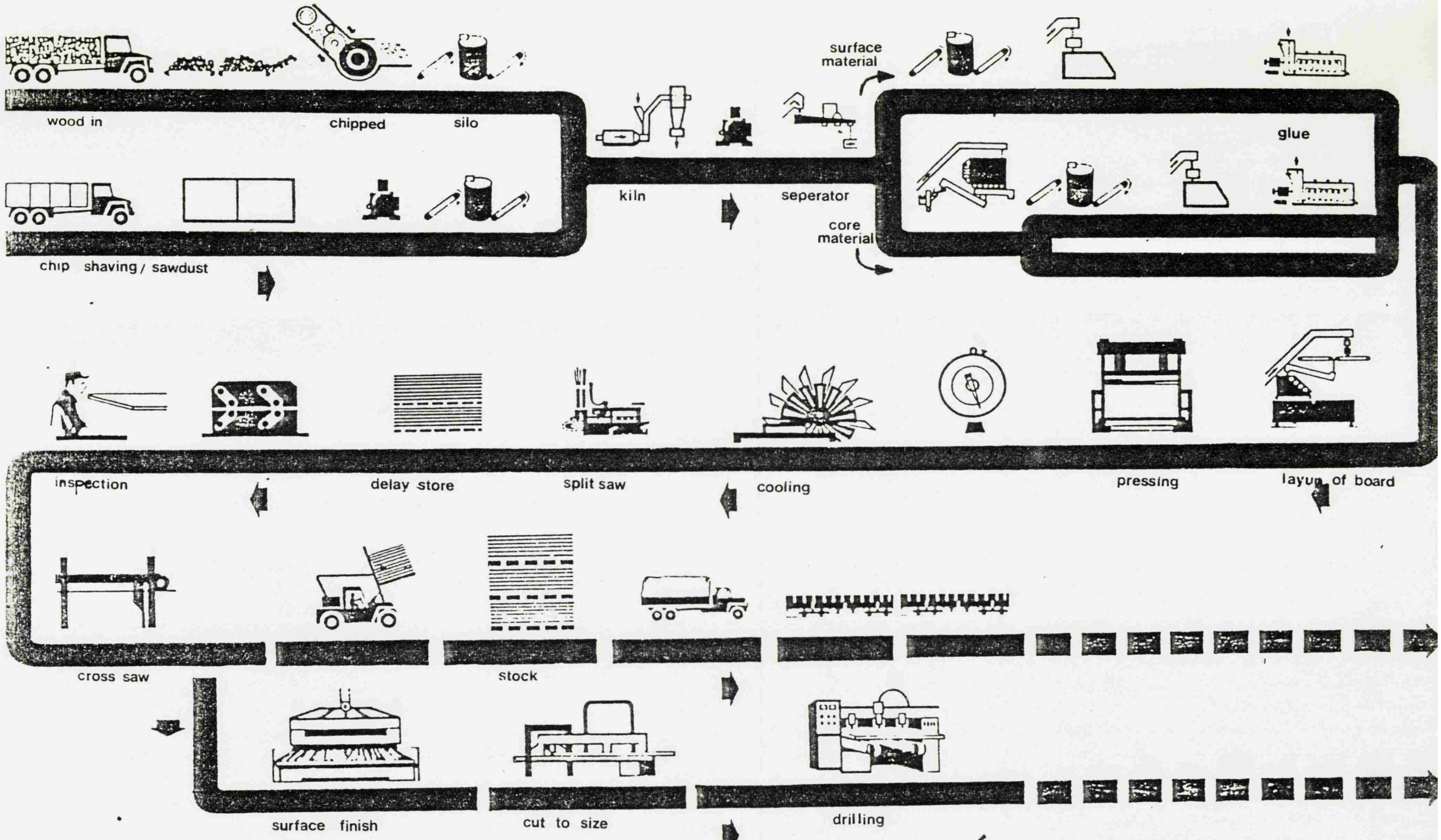


FIGURE 15 : CHIPBOARD MANUFACTURING CYCLE

4.2.3 Edge Waste within the Furniture Manufacturing Cycle

The Furniture Manufacturer has in effect two problems vis-a-vis controlling cutting waste levels and hence costs, namely:

(a) The first decision problem is related to what board sizes and quantities should be stocked; the Assortment problem.

(b) And the second is, given the board sizes and quantities, how to cut those stock sizes to meet the order demand; the Two-Dimensional Cutting Problem.

The most cost effective method is of course to design the panel sizes to match the board size. On many occasions, however the following industrial characteristics and peculiarities actively thwart such a simple solution from being adopted.

4.2.4 Marketing Characteristics.

The furniture industry is basically a fashion industry; ie. it is driven by the retail customer relationship rather than by the manufacturing/retail link. The specific furniture model size and hence the corresponding panel sizes and quantities is often controlled, therefore, by the retailer's notion of "Price Point Value". For example, living room wall units are categorised by length and price point value: A six feet six inches unit equates to a retail value of £199.99. If the furniture manufacturer reduces the overall length, in an effort to better match the panel sizes within the unit to the board size availability, then the retailer drops the price point value to the five feet six inches unit price, even though the actual size of the amended unit may well be six feet three inches, say. A further example relating to marketing/size restrictions is seen in kitchen furniture which is now nearly entirely manufactured to a BS dimensional specification.

These marketing constraints and pecularities result in the situation that the furniture manufacturer rarely has any significant control over the actual sizing of the product and hence the panel sizes. Therefore the straightforward approach of designing panel sizes to match specific board sizes, is often not possible.

4.2.5 Technological Limitations

There are two basic approaches adopted in the manufacture of chipboard:

(a) Small platten size of fixed length and width dimensions;

(b) Platten size which has a large length dimension, as long as ten meters, with constant width dimension;

and the majority of furniture manufacturers purchase boards from chipboard mills of type (b). The main reason for this is one of price and the fact that the furniture manufacturer is able to specify how the long board length is to be sub-divided. The only constraints imposed on the furniture manufacturers by the chipboard mill are that:

(b) the total board length must be purchased:

(b) that only two free cuts per board are permitted.

(c) the position of those two cross cuts must be constant, for a given board stack height quantity, ie. approximately 100 boards.

This situation then normally results in that three board sizes are stocked by the furniture manufacturer; two boards which are panel related and the third board which is termed the "faller" which often results in high wastage, low usage or both.

4.2.6 Purchasing Constraints

The purchasing of the raw material is often carried out on a three month forward order basis. The exact manufacturing requirements, model types and quantities, are not known until approximately three to four weeks prior to the start of the manufacturing cycle. In addition, given that the current methods of forecasting are based upon valuation. rather than on specific model/quantity analysis, the Purchasing Department receives little, if any, help in determining what sizes and quantities of chipboard should be ordered.

4.2.7 Design Limitations

Although designing furniture models to specific board sizes - given the retail constraints previously mentioned - at the design stage will obviously assist in reducing waste costs, only one model type, at a time being planned for at the design stage. Thus when tens of different models, from different ranges and of varying quantities, are manufactured together, the single panel size / quantity relationships, first planned around at the design stage no longer exist. This is not meant to be a criticism of the design function, rather a statement of fact that until the combinatorial implications of the manufacturing requirement are known, the cutting patterns which reflect the minimum total cost for the primary conversion operation, cannot be calculated.

4.2.8 Changes During Manufacturing

The manufacturing cycle of furniture involves many different operations, hence it can be of little surprise that mistakes will occur. The result being that cutting patterns, irrespective of where they originate from, get "amended" and some even omitted. For example, the low quantity requirements of the small panel sizes are often cut from larger panels which have been damaged or rejected for one reason or another, with the result that these cutting patterns are disregarded by the Mill personnel.

Although managements view is that the Planner, when determining cutting patterns, is predominantly concerned with waste minimisation, the industrial characteristics, as outlined above, are continually changing and evolving during the decision process. Hence the final decision on what cutting pattern will be used cannot be simply arrived at by the single attribute of waste levels alone.

4.3 COST OF CUTTING : VOLUME THROUGHPUT

Cutting costs can be defined as: The time taken to cut a specific volume multiplied by the labour costs required to complete the cutting operation.

It is self evident that the time taken to cut a specific volume depends on the following two key inter-related variables:

(i) The complexity level of the cutting patterns;

(ii) The type of sawing methods employed in the conversion process;

these two variables are now detailed.

4.3.1 Complexity of Cutting Patterns

The levels of cutting pattern complexity can be diagramatically represented as a decision staircase. At the bottom of the stairs, the cutting patterns are simple and require little time to be processed by either the Traditional or the Systemised sawing approaches. Each step up the staircase however, offers additional alternative levels of pattern complexity. Moving up (or down) the staircase results in both positive and negative effects. For example, moving up a stair may result in a reduction of material usage, due to increased pattern complexity. A positive effect then on material as waste levels decrease. There will however also be at least two opposite and opposing negative reactions. namely:

(a) The time required for cutting the patterns will increase

(b) And as a direct result from (a) there will be a reduction in the volume throghput, which in turn will negatively effect unit costs.

4.3.2 Sawing Methods

The sawing methods adopted in the manufacture of furniture are constrained by the cutting machinery available and the inherent design therein contained. For example, it is well known that the basic angular system concept cannot cope easily with Head-cut patterns. In addition T* type cutting patterns can only be cut by off-line sawing methods. In many cases then the determination of the upper limit on cutting pattern complexity levels is imposed on the Planner by the sawing machines previously purchased, rather than the other way round.

* See Appendix.

4.3.3 Determination of Cutting Costs

The determination of cutting costs, for cutting patterns and the implications for the volume throughput variable are not explicitly calculated by Planners. Rather the approach adopted centres around the Planners own specific "Economics of Cutting" heuristic. Basically, from practical experience the Planner knows that keeping cutting patterns simple results in low cutting costs but tends to increase the wastage levels. On the other hand, the more complex the cutting pattern, although having the effect of decreasing waste levels, increases the cutting time and more often than not also produces residual problems for the Mill.

The Planner then does not know and cannot possibly know if the selected level of pattern complexity for a specific order input equates to the minimum overall least cost. To arrive at such a position would require a total cutting pattern enumeration and cost evaluation exercise to be undertaken. Due to many factors, not least of which is the time requirement for such manual computations, such a suggestion is infeasible and hence Planners utilise their own personal defined heuristic and preferences system to interpret managements globally defined minimum waste objective.

4.3.4 Pattern Discontinuities

The degree of importance attached to the pattern discontinuities phenomenon ie. the effect of panel type A appearing across too many different cutting patterns - will largely depend on the manufacturing philosophy followed by the individual furniture manufacturer, ie.

Manufacturing to stock:

In the manufacturing to stock situation, the requirement for low pattern discontinuities is controlled by the next machine sequence requirement. Normally one or two days work in progress is between the saw and the next machining group; generally the fast panel processing tennoning and edge banding lines. Hence there is the possibility to re-sequence the panel spread from the sawing operation, if required.

A rule of thumb method for deciding whether the panel spread is acceptable or not in this situation is that as long as all the panels required are produced in the one shift then panel spread can be discounted. This solution procedure however, whilst minimising the Planners aggravation, tends to result in maximum problems for the labourers at the rear of the sawing machines, who are required to handle and sort the cut panels into like machining groups and also takes little account of the W.I.P. buffer stock costs.

Manufacturing to order:

In the manfuacturing to order situation, the requirement to have little or no pattern discontinuities assumes a far greater degree of importance than is initially apparent. In following this manufacturing philosophy, the work in progress between the machine groups is often dictated to by the batch/marketing concept followed and the delivery dates/geographical area that the furniture is destined for. Given that the work in progress will be low, panel sequencing becomes exceedingly important. Thus it is not uncommon to find that the whole panel sequence for the factory is carried out at the sawing operation. In such situations the planning heuristic used is as follows:

1. In determining cutting patterns only one panel type is permitted on a cutting pattern. This rule is modified if;

(i) A second panel type can be added as long as its order requirement can also be satisfied;

(ii) Where the waste, with one panel type, exceeds the upper waste level imposed by management, then an additional panel type can be included in the cutting pattern. Generally this second panel type can be spread across three to four cutting patterns.

2. On completion of generating the cutting patterns, the next requirement is to arrange the

patterns into some form of order sequence for the next operations. Generally the larger panels; ie. panels which have long length and width dimensions are sawn first wherever possible. The major reason being that the next operation, which is tennoning and edge banding are faster than the saw. These larger panels therefore provide a higher volume output per hour with less sawing time. Thus by completing the sawing of these panel types first, the work in progress (really the queue to the next machine type) is effectively filled.

3. The next panel types that the Planner considers are generally the panels with the longest operations. ie. drawer fronts, doors and shaped panels. These panel types require much longer to process and hence are required as early as possible.

In the manufacturing to order situation then the Planner adopts various strategies in an attempt to overcome the difficulties associated with panel discontinuities. In practise it was not unusual to find that the Planner was prepared to trade-off wastage to relieve the manufacturing system of the pattern discontinuities problem.

The Panel Manufacturer

The panel manufacturer, who makes to customer orders has a more complex problem vis-a-vis pattern discontinuities. On the one hand he has to meet priority of order delivery whilst taking as large a set of orders as possible, such that the mixing of orders will reduce the total board usage. On the other hand little work in progress is held and the panel order price may well be tied to a specific delivery date. In addition, panels which are cut too early result in stocking and additional handling costs and also have a cost associated with the missed opportunity in obtaining a better mix of panels which might have reduced the level of board waste. The objective then for the Panel manufacturer is not only to have low wastage levels but also to have zero pattern discontinuities: a conflicting set of objectives.

The overall consideration given to pattern discontinuities at the initial generation stage of cutting patterns centres around minimising the maximum aggravation caused for both self and others. Hence in many practical situations Planners adopt a trade-off approach within their respective pattern generation technique and as such the pattern discontinuities that appear from linear programme solution approaches rarely occur.

4.4. SUMMARY

As can be seen from the details of the significant technology components, the furniture manufacturers 2DC problem cannot be modelled around the single decision criterion of waste minimisation alone. It is essential that any proposed solution to the problem incorporates these previously described technology components. Their inclusion in the model however, should not be solely to restrict the feasible decision region or to simplify the problem so that it matches a known modelling technique. In the course of our research we have discovered that these technology components are used, by Planners, to explore the total decision space of the problem in a more effective way than one pre-supposes. The result being that the manually generated cutting pattern sets of the Planner are often far superior to those generated by computer models. The main reason for this is that the Planners decision space is not confined to the simple static plane of waste minimisation but is multi-dimensional and dynamic. The Planner is required to balance between many competing objectives that depend on the same or similar control variables : the objective being determined not by one but by many decision criteria. Given these circumstances, contradictions are bound to arise between the different, competing objective functions. These contradictions are a natural phenomena and occur because the different decision criteria assume optimal values at different points in time within the common decision space. In such circumstances the Planner becomes the arbitrator of what is or is not acceptable. In many situations the process of arbitration will modify the original problem boundaries, eg. additional panels will be added to the order list, or additional extras will be added.

The previous mathematical solution approaches to trim problems have failed to recognise that although the cutting pattern problem is definable in mathematical terms, it resides in an environment that is very loosely structured. The exact definition of the problem and the decision criteria used in arriving at a solution will vary and are heavily dependent upon the Planners perception of what is considered important. It is therefore essential to consider how Planners perceive their cutting problem and more importantly how they link together the mathematical and technology components of the problem. In the following chapter therefore, emphasis is given to determining and understanding the decision making process of the Planner.

CHAPTER FIVE : THE PLANNER'S DECISION MAKING PROCESS

5.0 RE STATEMENT OF THE 2DC PROBLEM

Considerable surprise is often expressed by Operational Researchers when examining the difference between the manual and the computer generated cutting pattern results. The main reason for this surprise is that the manually generated cutting patterns are considerably less in number and are very close to the optimum wastage levels generated by the computer solutions. Given that the objective function of the Planner is to generate cutting patterns which satisfy multi-dimensional decision criteria rather than the single decision criterion of waste alone, it is of little surprise that the manually generated cutting patterns are preferred. In this chapter we therefore examine the manual methods and approaches adopted by Planners in structuring their multiple decision criteria 2dc problem.

In the problem that is being considered : the two dimensional cutting problem of the furniture manufacturer, the Planner is faced with determining cutting patterns which effectively attempts to balance and satisfy the following decision goals:

* WASTE:
* VOLUME THROUGHPUT:

* PANEL SPREAD ACROSS CUTTING PATTERNS:

* SETTING TIME : RELATES TO THE NUMBER OF CUTTING PATTERNS:

* HANDLING AND SORTING AT THE OUTFEED OF THE SAWING MACHINE

The approach adopted by the currently available computer models in satisfying these goals is orientated towards the classical linear/dynamic programming formulation of Gilmore and Gomory (22) ie. a two step solution procedure where the first step is the generation of strip combinations - the linear programme - and the second is the loading of these generated strips on to the available board sizes - the dynamic programme. This two stage mathematical solution approach however causes residual problems in the following areas:

(a) the number of cutting patterns to panel input is generally in the ratio of 1:1.

(b) there is no method available to set the cutting patterns to run length.

(c) there is no method for sequencing panels to specific cutting patterns.

(d) the setting time and time taken for sawing each cutting pattern is not known until after the cutting pattern has been decided upon and hence cannot be included within the linear programme fomulation solution.

These problems then are the main reasons cited as to why only a few computer based solutions to the furniture manufacturers 2dc problem currently exist. According to the majority of Planners, although wastage levels are an important and significant variable they are by no means the only decision criteria that is used to evaluate the acceptability or otherwise of cutting patterns. In practise the final decision evolves through a process of understanding that the real decision problem is related to searching for the cutting pattern set that is most attractive over all dimensions of the decision space contained within the problem boundaries.

Given that the furniture manufacturers 2dc problem has these multiple decision criteria we were concerned to identify and answer the following questions:

(a) How does the Planner structure his cutting pattern problem?

(b) What solution strategies and techniques are used to enumerate and evaluate the feasible pattern combinations?

and it is these two questions that are now addressed in the remainder of this chapter.

5.1 THE PLANNERS MANUAL APPROACH TO THE 2DC PROBLEM

Certainly a first step might be to consider the attributes of each of the previously specified goal alternatives, in terms of achieving some overall minimum cost objective. However, the Planner, in attempting to choose from amongst the alternatives will almost certainly find that although one alternative is preferred when one specific attribute is considered, another alternative will be preferred when a different attribute is considered. For example, if material costs become the attribute that concerns the Planner most, then the goal most appropriate would be the level of waste. From a practical point of view this could lead the Planner to increase the level of pattern complexity. This would result not only in a reduction of material but also additional time being required at the sawing operation. ie. a reduction in volume throughput, given that the panel and board order sets are both constant. If on the other hand the attribute changed to maximising the units of furniture produced in a fixed time, then volume throughput would become the dominant goal. This could easily be achieved by relaxing the pattern complexity level from multiple stagger to simple cross-cutting. The gain in volume throughput however is at the expense of higher board usage - an increase in waste levels.

Rarely then will there by one alternative that is best for every attribute that contributes towards the Planners overall decision objective. Hence in practise we have found that the Planner is often forced to accept lower values on some of the attributes thereby obtaining higher values on the remainder, ie. a compromise or trade-off approach to the cutting pattern decision problem, rather than an optimization approach.

METHODOLOGY.

During our research we worked with six Planners in three different Furniture Companies.

The methodology adopted in identifying the characteristics and the attributes used by these Planners when generating cutting patterns was based on the following:

1. Each Planner manually generated five sets of cutting patterns: the panel and board sizes for each being different.

2. The same data set and restrictions were modelled using a normative L.P. model and five sets of 'minimum wastage' cutting patterns produced.

3. By interview. each Planner was asked to critically appraise the computer solution in the light of his own pattern set.

4. The major areas of difference between the manually and the computer set of cutting patterns were synthesised into a set of decision rules which were later encoded into a Pascal programme. These decision rules are further expanded in Chapters six and seven.

The overall objective of this methodology being to provide a model of how Planners actually generate cutting patterns rather than provide a normative model of how they should work; the L.P.approach.

5.1.2. Information Filtering and Pattern Fit Approach.

During our research it became quite clear that many Planners ignored much of the information that is considered essential by the Operational Research fraternity for the successful modelling of the 2dc problem. As we have previously indicated rather than waste minimization being the solution base, Planners carefully consider two or at most three major goals and their associated attributes in an attempt to achieve satisfactory cutting patterns which are acceptable for the whole system. The approach adopted by Planners, in determining cutting patterns then, is firmly orientated towards a solution which balances the whole system in general terms and not the waste minimization goal that is suggested in the current literature.

Further observations indicated that wastage levels were not explicitly considered by the Planners in their initial deliberations around the problem of pattern generation. Rather the start point is more likely to be based upon a pre-decision information filtering process. This pre-decision process matches the Planners internalised library of good cutting patterns to the current order set. These good cutting patterns have been established over a number of years and reflect cutting patterns which are acceptable to the overall system decision goals. Occasionally, due to the combinatorial effect of the given order and or board set, the initial panel data - ie. sizes of the paenls and the quantities requried - are required to be modified thereby effecting a pattern fit to the Planners good cutting pattern set.

The significance of this a priori pattern matching approach should not be overlooked or under-rated. The cutting patterns generated by this method are often the crucial cutting patterns that facilitate the reduction of the number of cutting patterns to the panel order input: the major weakness of the linear/dynamic programming approach, as illustrated in the following example.

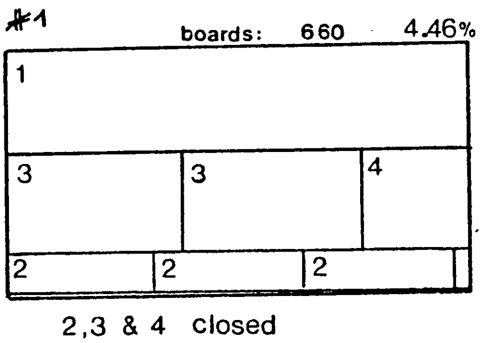
EXAMPLE 1

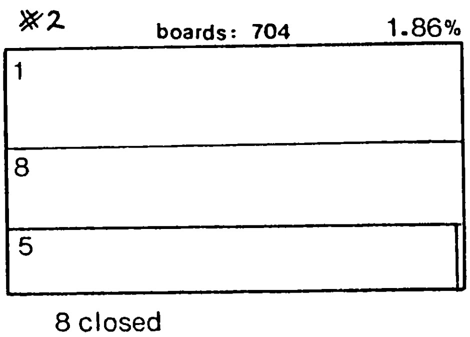
The following panel sizes and quantities are required to be cut from a board size of 1930 x 1250:

Panel Sizes	Qty	Panel Sizes	Qty
1) 1921 x 512	1946	2) 616 x 200	1980
3) 737 x 498	1320	4) 437 x 498	660
5) 1887 x 313	1286	6) 677 x 413	1164
7) 530 x 413	582	8) 1921 x 413	704

RESULTS:

The Planners pattern fit approach resulted in 1946 boards of 1930 x 1250 being used with only three cutting patterns being required. In running the same problem on the Opticut computer model (   ) which is based on an LP linked dynamic programme the number of boards required was also 1946. The number of cutting patterns generated however were four. The actual cutting patterns of the Planner and from the computer model are given in figures 16 and 17 respectively:





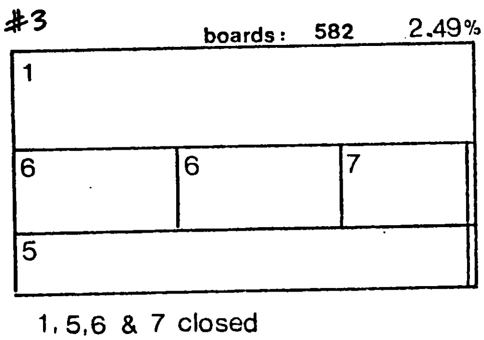


FIGURE 16.0 MANUAL CUTTING PATTERN : EXAMPLE 1

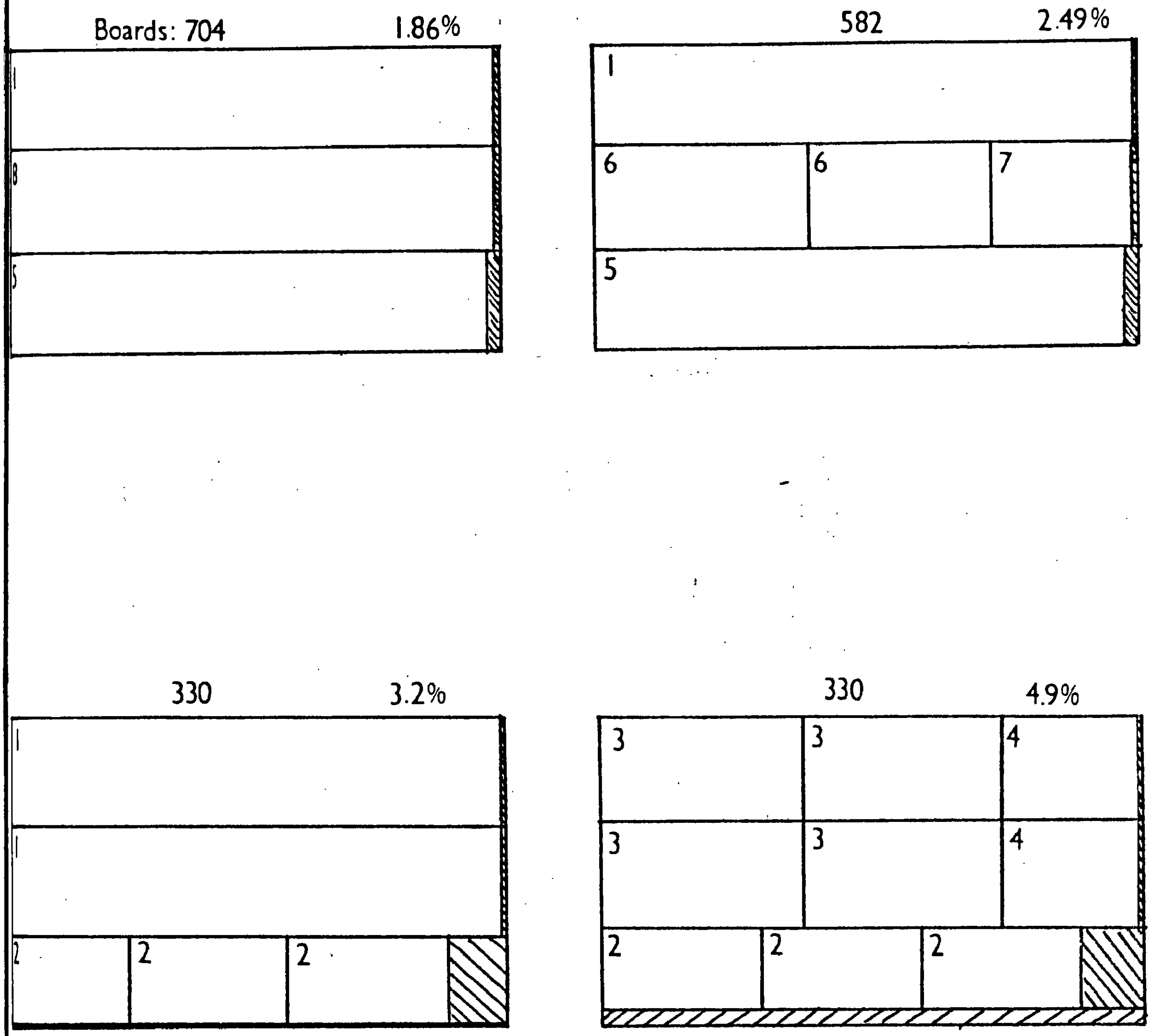


FIGURE 17.0 COMPUTER GENERATED PATTERNS : EXAMPLE 1

5.1.3 The Planner Explains:

In analysing the result from example 1 with the Planner at a later stage, the following points emerged which go some way to explaining the thinking process that this Planner used in structuring his decision space and hence in generating the cutting pattern set.

" .... I know my first cutting pattern isn't optimal from a wastage point of view. It would have been better for example to have two 512mm ends combined with the 200mm drawer fronts. This combination, however, would result in smaller run quantities due to the same panel being nested twice on the same cutting pattern. In addition, because of the board / panel size relationship, I know from previous experience that a smaller number of patterns will often result if my first pattern out has three different strip types on it. Yes, I agree that the wastage will probably go up by adopting such a start point, however, I can always come back and start again or modify the panel quantities slightly so that the wastage level is maintained within reasonable limits. And as you can see once this first pattern is completed the other cutting sheets fall out easily, don't you agree?..."

This simplistic explanation gives some insight into the reasoning process used by this Planner in structuring his 2DC problem. A point of significant interest is the fact that the initial problem structure base for generating the cutting pattern set revolved around his practical knowledge base about the panel, board relationships and not levels of waste.

In addition to this pattern fit first stage, our research identified the following six major decision components that Planners make use of in structuring the decision space boundaries, re their 2DC problem:

1. Pattern Complexity Level/Library Cutting Patterns:

The first decision component considered is associated with determining the level of pattern complexity that is appropriate for the system and the implication of utilising the library file of personalised cutting patterns.

2. Identification of the Current State of the Environment:

This component refers to the identification of the environmental characteristics that go to bound the actual cutting operational area. For example, the amount of storage between the various machine groups; the state of the order book; the significance or otherwise of the panel mix on the machine availability the assembly/despatch requirements.

3. Economics of Cutting Heuristic:

Each Planner will have a personalised cutting heuristic which facilitates the measurement of pay-offs - likely to be thought of as advantages verses disadvantages rather than a numerical measurement which results from the possible cutting pattern combinations for each panel order set.

4. Robustness of Current Information:

As previously mentioned, the Furniture Industry can be thought of as a fashion industry which is continually changing to meet consumer demand. Hence the Planner has to pay particular attention to the robustness and the reliability of the current sales order information. For example, it is not unusual for the sales forecast to be totally reversed one or two days prior to the cutting operation.

5. The Games of Cheat:

All manufacturing systems provide their members with various options for cheating and the Furniture Industry is no exception. eg. Although there are a set of defined rules relating to the levels of pattern complexity that the Planner will permit, it is quite common, when analysing manually generated cutting patterns to see these rules amended, disregarded and new rules added.

6. The Stopping Rule:

The determination of cutting patterns is often delegated to the production planning department. Like many other line functions within the Furniture industry little time is available in which to analyse and formulate the total set of decision alternatives; in this case cutting patterns. Hence the stopping rule revolves around the amount of time available rather than some idealised scenario about time cost benefit analysis.

5.2 MANUAL SOLUTION STRATEGIES & TECHNIQUES:

In addition to the pre decision stage it also became evident that the Planners approach to the actual generation part of the 2dc problem - the second phase - was in part similar to the [[IF ... THEN]] approach used in the area of Artificial Intelligence and Expert Systems. ie. As we have previously mentioned each Planner will have his own finely tuned set of rules, which will reflect what he and others, within the organisation, consider to be the important goals. For example, one Planner that we worked with during our research categorised some of the main decision goals that he considered during the pattern generation phase of the 2dc problem as :

----
* GOAL *   MAXIMISE THE NUMBER OF BOARDS PER CUTTING PATTERN.

REASON : ..... High set up time for sawheads to be repositioned when cutting patterns are changed.

EXPLANATION : .... Because the saw is an integral part of the flow press line, it is essential that the number of set ups, which can take up to 0.6 hour is kept to a minimum.

----

* GOAL * MINIMISE THE PANEL SPREAD ACROSS THE CUTTING PATTERNS.

REASON : ..... causes sequencing problems and proves awkward from a materials handling point of view.

EXPLANATION : ..... space is at a premium. Thus outfeed conveyors at the rear of the press and the main saw group are limited. This means that the storing and waiting to panels that are nested on four and five cutting patterns proves very aggravating for many other departments.

----

* GOAL * USE BOARD SIZES THAT MAXIMISE THE PRESS PLATTEN SIZE.

REASON : ..... maximises volume throughput at the flowline press operation.

EXPLANATION : ..... approximately 70% of our furniture range is required to go through the flow line press. With only one press, pressing small board sizes, which only marginally reduce waste levels isn't on.

5.3 NETWORK OF RULES

These decision goals; reasons and explanations then, indicate only a small sub set of a much larger network of rules utilised by this Planner in generating his cutting pattern set. The decision on what operational strategies to apply are obviously suggested by the current situation and industrial characteristics within a specific company, as indicated by the second phase within the decision process. For example, the Planner previously cited, in attempting to satisfy the multiple goals of:

(a) maximise the number of boards per cutting pattern;

(b) select cutting patterns that have high number of order closures, given an upper waste threshold limit;

was able to adopt one or more of the following strategies, when generating his cutting pattern set:

5.3.1 * Rule / Condition 1.

IF : < condition >

The current board run quantity is too small .. and it is not possible to bring other panels forward ... or to buy in cut sized panels from an outside supplier;

THEN : < action >

1. Use reclamation route for board runs of <25 ......or

2. Use bought in pre finished boards for medium size board quantities. ..... or

3. Decrease the current order quantities such that the offending panel is not required.

5.3.2 * Rule / Condition 2.

IF : < condition >

the wastage figure is above the threshold limit and the maximum pattern complexity level is already reached;

THEN : < action >

1. accept smaller board size, which will reduce both wastage and volume through the press ..... or

2. bring forward panels not previously batched.

5.3.3 * Rule / Condition 3.

IF : < condition >

number of cutting patterns are too high in number and number of boards per cutting pattern are medium to average, ie. 250 / 400;

THEN : < action >

1. increase pattern complexity ..... or

2. increase certain panel type quantities ..... or

3. add additional panel types not previously considered to the batch ..... or

4. add new models to the batch to increase panel variability.

5.4 GOAL ORIENTATION OF THE PLANNER

It is evident from the above information that Planners do not and cannot explicitly consider all the possible cutting pattern combinations but reduce those alternatives down to a feasible sub-set of alternatives. Our research suggests that although the major goals sought by the Planner, in the 2dc generation phase, will obviously depend upon the industrial constraints and the internal company environment, the following three decision goals, which go to form the boundaries of the decision space, are considered as the kernel of their pattern generators:

GOAL 1. Minimise the number of cutting patterns to panel order inputs;

GOAL 2. Minimise a panel order from being spread across too many cutting patterns;

GOAL 3. Given the above goals of 1 and 2 generate cutting patterns which have the lowest possible waste levels.

The degree of importance attached to each goal is dependent upon the state of play that exists within the company at a specific point in time. For example, if increased volume is required from the primary conversion operation and overtime is not possible, then cutting patterns which have a lower pattern complexity level could be selected. In such circumstances the Planner is required to balance and trade-off the advantages gained from satisfying one goal against the disadvantages that result in the other goals.

5.5 STRATEGIES ADOPTED IN MANUAL CUTTING PATTERN GENERATION

From our detailed research it is possible to outline the following strategies that are used by Planners within the U.K. Furniture Industries when given the problem of generating cutting patterns:

Strategy 1

Make use of own pre-determined set of good cutting patterns, first;

Strategy 2

When enumerating strips, utilise panel combinations that can be correctly factored, so as to close more than one panel order per strip, even if the strip wastage increases by one or two percent;

Strategy 3

When combining strips onto board widths utilise strips defined by S2, which satisfy goals G1 and G2, in preference to single strip types which have less wastage;

Strategy 4

After each generation check for new cutting patterns which can be added to the library of good cutting patterns.

The identification of these strategies, and there were others, supports our belief that rarely do Planners determine cutting patterns by working everything out from first principles, in the same way that the current computer solution models do. Rather the Planners approach, which is multi-staged is more likely to be based on the following modus operando.

1. The usage of a pre-conceived library file of good (ie. acceptable) cutting patterns, which are based on the individual planners level of acquired experience and understanding.

2. A recursive problem reduction algorithm which is based upon the previously described three goals, G1, G2, G3.

3. Given that these goals will often conflict with one another; ie. it is not possible, unless specifically designed for, that cutting patterns will offer low wastage and high volume, then the Planner

uses a set of internalised actions, (strategies) in an attempt to arrive at a set of cutting patterns that are acceptable for the whole system. These strategies form the basis which enables the Planner to compromise between the competing objectives within the problem and are often based upon the technology components rather than the decision goal of waste minimisation. This latter goal only being used as an indicator to assist the Planner in identifying the upper boundaries of the multi decision space.

5.6 SUMMARY

In summarising our enquiry into the Planners decision making process, probably the most important disclosure of all is the identification of the existence of the Planners decision making strategies and the fact that Planners typically make use of pre-conceived cutting patterns. In addition the pattern generation phase is based on a heuristic, problem reduction approach, which incorporates specific rules. And it is these rules/ strategies that the Planner uses to ensure that the generated cutting patterns are acceptable to the total system.

Currently much of the Planners knowledge base is ill-defined and operates from within a sub-conscious level and hence has seldom, if ever, been documented or recorded; the main reason for this we suggest is that too little time has been spent in understanding the real world cutting pattern problem and too much making it fit into the linear optimisation model type box. As our worked example on page 123/4 illustrates, current computer models are no match for Planners who start with the dual advantages of (i) a related knowledge base that is plainly impossible to model via the L.P. approach and (ii) the ability to modify, change and invent new decision rules as they search through the decision space. This detailed knowledge base, combined with the ability to manually explore the decision space reasonably effectively leads us to contend that a more appropriate solution to the Furniture Manufacturers 2DC problem lies in structuring the problem via a suite of problem related heuristics. The main objective of this approach being to improve the decision making process of the Planner rather than to generate cutting patterns with minimum waste.

CHAPTER SIX PROBLEM FORMULATION PART 1 : MODEL STRUCTURE

6.0 THE REAL WORLD SITUATION

Central to our approach is the belief that the real situation confronting the Planner is more complex than the normative two dimensional cutting problem cited in the literature. These previous studies have generally focused the majority of their attention on the minimisation of material used. Where specific industrial characteristics have been included; knife change, number of setups and sequencing, the central core of the approach still remains as a linear programming - knapsack base. It is our contention however that not all of the trim problem characteristics are quantative, and even where they are, they cannot be treated in a strict linear fashion. In addition, the utilisation of qualitative industrial characteristics which are often used as constraints in the formulation of the linear programme fails to recognise, and hence tackle, the complex inter-related nature of the linear and non-linear characteristics contained within the trim problem. In this chapter therefore we identify and formulate a model structure which has been fashioned from understanding how the Planner manually generates cutting patterns.

6.1 MULTIPLE PROBLEM CHARACTERISTICS

From informal interviews with a number of Planners, with whom we worked, the multiple goals that they all considered as being essential to their respective 2DC problem were identified as being:

1 - Level of waste;

2 - Level of volume throughput;

3 - The ratio of cutting patterns to panel orders required;

4 - Minimisation of panel cutting pattern spread;

These primary goals, however, are a product of the specific Company/Planner and although important fail to give any insight into how the Planner actually structures his 2DC problem so that these goals may be realised. To gain an understanding of the Planners actual decision making process it was necessary to identify the characteristics inherent within cutting patterns that bounded the problem and which supported the achievement of the individual primary goals. These characteristics were identified over an extended period of time, working directly with the Planners. The results of that research can be seen from the following table:

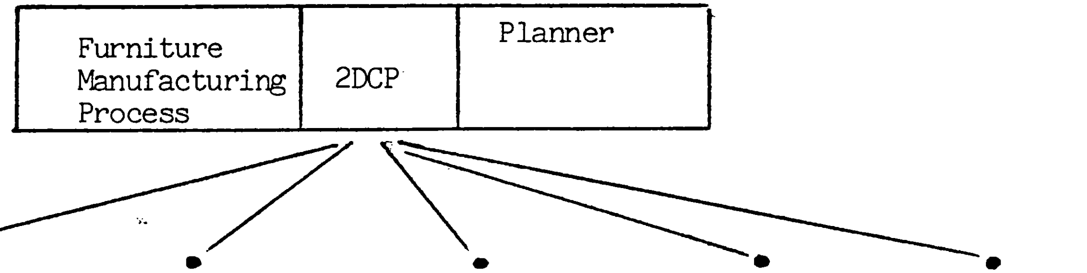
CUTTING PATTERN CHARACTERISTICS	COMMENTS:
1. WASTE	Main concern was to achieve a waste threshold level; different than minimum waste criterion.
2. VOLUME	Realisation by Planners that volume is a function of given panel order set and level of pattern complexity.
3. PATTERN COMPLEXITY	Difficult concept to ascribe a mathematical value to. Used differently by different Planners. Should reflect the differential costs between the cost of waste and the cost of sawing.
4. PANEL SPREAD	Each Planner will have his own heuristic about the level of panel spread. In general the panel spread will be time related; ie. must be completed in X hours or will be a direct number ie. panel A can appear on no more than four cutting patterns.
5. NUMBER OF DIFFERENT PANEL TYPES IN STRIP	The level set increases the potential number of cross cuts and hence reduces volume throghput.
6. NUMBER OF DIFFERENT STRIP WIDTHS	The design of the saw and the layout at the rear of the machine influences this variable.
7. BOARD RUN LEVELS	Implications on machine utilisation and hence output efficiency. Largely dependent upon four charactertics * Sales order level * design of furniture to boards * the diversity of panel types in strip and the different strips on cutting pattern
8. DESIGN PANELS TO BOARD SIZES	>

9. BATCH SIZES	>	THESE ARE THE GIVEN PROBLEM CONSTRAINTS AND ARE GENERALLY OUTSIDE THE PLANNERS DOMAIN OF CONTROL
10. MAKE TO ORDER/STOCK	>	
11. SAW DESIGN		
12. PURCHASING CONSTRAINTS	>	

TABLE 2.0 PROBLEM CHARACTERISTICS

These problem characteristics can be further refined into a set of operational attributes which specifically support one goal rather than another. In practise we found that the majority of the attributes were directly tunable, by the Planner, although some appeared less direct than others. For clarity we have diagramatically represented, in figure 18.0 the concept of multiple goals and the attribute space that the Planner works in.

Figure 18.0 is important as it illustrates the attribute space of the Planner and indicates how those attributes can be grouped together thereby forming the base which enabled the Planner to enumerate cutting patterns.



	WASTE MINIMISATION	MAXIMISE VOLUME	HIGH PATTERN RUN LENGTHS	MINIMISE NO OF CUTTING PATTERNS	MINIMISE HANDLING & SORTING
MULTIPLE GOALS: In practise the Planner is required to balance these operational goals:					
ATTRIBUTE SPACE: Decision Space that the Planner works in. Defines the tech-noligy components that enables the the Planner to balance between the competing, multiple goals, when generat-ing cutting problems	Set Wastage Threshold limit Set pattern complexity level board; panel size relation-ship work in progress	saw design batch size work in progress	increase strip complexity levels increase cutting pattern level of complexity minimise number or different panel dimensions	Trade-off X% waste for reduction of n cutting patterns *CHECK* (i) volume threshold L (ii) W.I.P. (iii) Urgency of closure	Storage at rear of saw work content of panel buffer WIP between M/C groups

FIGURE 18.0 DECISION SPACE OF THE PLANNER

6.2 EVALUATION OF A CUTTING PATTERN:

By analysing the problem characteristics and the constraints imposed by the sawing technology; see Chapter Four, it is possible to identify the main variables that are required to be taken into consideration at the model building stage. These variables can be categorised into the following types:

```
------------------------------------------------------
TYPE   RELATING TO MATERIAL
------------------------------------------------------
m 1.  ROTATIONS ALLOWED?< yes/no and default yes for
a                       < certain panel types.
t 2.  TRIM REQUIREMENTS? < length - front edge?
e                        <        - rear edge?
r                        < width  - front edge?
i                        <        - rear edge?
a                        < head cutting additional trim
l                        < across width of board.



------------------------------------------------------
TYPE RELATING TO PATTERN COMPLEXITY: SAWING MACHINES
------------------------------------------------------

s 3. SAW PATH WIDTH       < dimension of saw blade.
a 4. LEVEL OF CUTTING     < head cut; complex or simple?
w    PATTERN COMPLEXITY   < multi staggered; z cutting
i    THAT SAWING M/C      < single staggered z cutting
n    CAN CUT              < simple checkerboard; z cut?
g
   these levels of pattern complexity can be further
t  defined from;
e  (a) number of different strip types on cutting pattern
c  (b) number of same strip widths on cutting pattern
h  (c) number of different panel types in one strip
n  (d) number of same panel types in one strip
o  (e) number of different panel types on one
l      cutting pattern.
o
g 5. SETTING TIME FOR EACH CUTTING PATTERN
y
   (f) time required to change board sizes
   (g) time required to reload with same board sizes
   (h) time required to input change of instructions
```

TYPE	RELATING TO COSTS
c 6.	- Cost of cutting at specific levels of pattern
o	complexity
s	- Material costs per m2
t	- Total number of operatives employed in the
s	primary conversion operation.
c	- Hourly cost of labour and overheads.
o	- Costs associated with producing extras.
s	- Costs associated with the spread of panel i
t	across too many cutting patterns.

TABLE 3.0 CUTTING PATTERN VARIABLES

4.3 GLOBAL CHARACTERISTICS

From the information given in tables two and three, it is now possible to identify the following six global characteristics that describe a cutting pattern;

1 - Level of cutting pattern complexity; ie. the level of cutting pattern complexity that the Planner is prepared to accept. The alternatives available to the Planner can be simple represented by a decision staircase as shown in Figure 19.0.

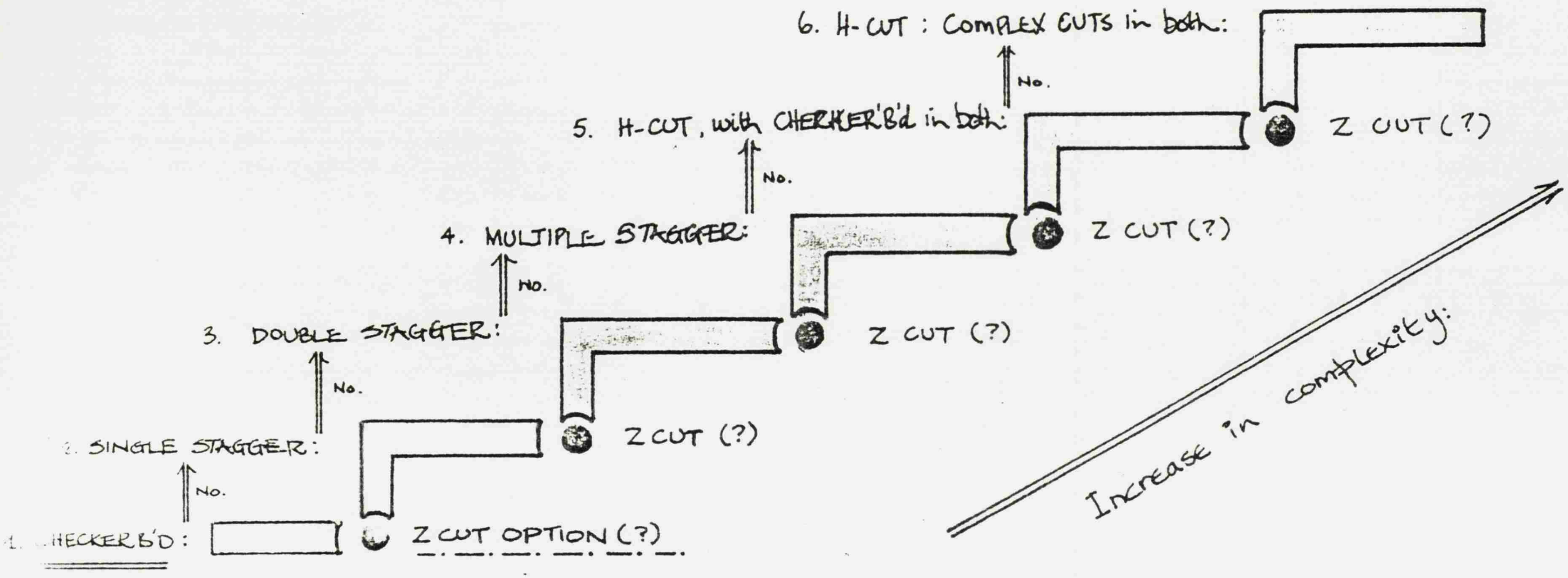
2 - Board run lengths: lower cutting pattern run lengths result in poor machine utilisation. ie. high set up time to low machining time requirement.

3 - Spread of a particular panel order across too many cutting patterns.

4 - Number of different panel types on one cutting pattern.

5 - Cost of raw material and levels of edge waste.

6 - Cost associated with cutting panel set P(i) from given stock boards B(i).



* This decision staircase illustrates the various steps in pattern complexity available to the Planner.

FIGURE 19.0 DECISION STAIRCASE* - PATTERN COMPLEXITY LEVELS

6.4 DECISION STRATEGIES : HOW USED BY THE PLANNER

Dependent upon the decision situation confronting the Planner, the previously cited global cutting pattern characteristics will be viewed and used quite differently. For example, given the situation of low sales orders more time is available at the sawing operation, hence in theory, more complex cutting patterns, which reduce the wastage levels, can be cut. The global characteristics being considered in this case are, (1) Wastage levels and (2) Volume throughput. In an effort to understand how Planners 'think-what-to-think-about' when confronted with the problem of pattern generation numerous discussions were held with a cross-section of Planners from the Furniture and Packing Case industries. From these discussions, the following decision goal and strategies, which Planners use to structure their thinking processes and aid their heuristic search of the decision space, were identified:

Goal No.1 CUTTING PATTERNS ARE REQUIRED TO HAVE ACCEPTABLE LEVELS OF WASTE

The key work here is 'ACCEPTABLE'. This is not the same as minimum waste level possible. In practise we find that the wastage level is managerially defined only at the product costing stage of manufacture. In many Furniture and Packing Case companies however little or no control information is available to check whether this theoretical wastage limit is ever achieved in practise. In reality therefore the Mill manager often becomes the sole arbitrator of what is 'Acceptable' or not.

Goal No.2 PANEL ORDER SHOULD NOT BE SPREAD ACROSS TOO MANY CUTTING PATTERNS

Basically, the requirement is for a panel order to be started, (opened) and completed, (closed) on the same cutting pattern. Following such a procedure in practise however, often results in large off-cuts being produced which have to be re-cut into smaller panels such as Plinths, Rails and Packing Strips. These smaller panel types, however, are only required in limited quantities and hence the large off-cuts, if produced, would soon become a visual embarrassment for all to see. These practical requirements then force the Planner to permit the inclusion of additional panel order tyeps onto a single cutting pattern. Now unless the panel requirements, for the different panel types are identical or their respective quantity combinations can be easily factored, then only one panel order type will be closed per cutting pattern. The result is that the other included panel order types which remain open on the cutting pattern, are carried forward for consideration on the next cutting pattern.

The degree of order spread permitted by the Planner is likely to be related to the number of outfeed storage positions at the rear of the saw and the time buffer that exists between the sawing operation and the next. As the spread of the panel order encroaches on these two variables, the degree of urgency to close the panel order increases. This urgency is reflected in the increased amount of edge waste; ie. larger amount of off-cuts than normal, that will be permitted to effect the panel order closure.

Goal No.3 CUTTING PATTERN RUN LENGTHS SHOULD BE AS HIGH AS POSSIBLE

The main reason why this strategy is used by Planners is to ensure that the machine utilisation of the sawing operation is actively considered when generating cutting patterns. For example small pattern run lengths increase the amount of non-productive time and hence the volume requirement per unit of time at the sawing operation only increases. In addition cutting patterns which have too high run lengths, due to many different panel types being included, may not be ideal either. On the other hand there is little to be gained from having pattern run lengths that are so long that the next machining operation has to wait. The Planner then attempts to balance the requirement of this goal to ensure that no residual problems result in the following areas: Machine utilisation: Volume throughput: No waiting time occurs at the next manufacturing operation.

Goal No.4	AVOID GENERATING CUTTING PATTERNS THAT RESULT IN SMALL ORDER QUANTITIES REMAINING

Planners actively discard cutting patterns that result in low quantities of order quantities remaining, even if the wastage levels are below the acceptable, managerially imposed limit. The main reason for this is due to the aggravation that small board runs cause at the sawing operation. ie. reduces volume throughput and lowers machine utilisation. In practise if no alternative cutting pattern is possible then the Planner may well increase or decrease the order requirement, thereby eliminating the small run problem.

6.5 SUMMARY

These then are some of the decision structures that are used by Planners in thinking what to think about, when structuring their two-dimensional cutting problem. It is clear from this detailed research that much of the information that is considered essential by the Operational Research fraternity, for the successful modelling of the two-dimensional cutting problem, is ignored by the Planners. Rather than waste being the absolute goal, Planners carefully consider two or at most three major goals and their associated attributes in an attempt to achieve satisfactory cutting patterns which are acceptable to the whole system. Hence the approach utilised by the Planner in determining cutting patterns is firmly orientated towards balancing and satisfying the whole system rather than trying to obtain optimality for one specific operation within that system ; the cutting operation.

The above information on the requirements of model structure points to the fact that Planners require help and support to sort through their respective 2DC problem rather than models which are optimal from a wastage criterion. The requirement then is to generate and evaluate the value of the cutting pattern based on all of the problem characteristics, not just the linear ones. The heuristic search problem reduction method that we now propose allows the Planner to examine all the possible goals; and their resultant trade-offs at each level within the pattern generation routine.

CHAPTER SEVEN: PROBLEM FORMULATION: PROPOSED SOLUTION APPROACH FOR THE TWO DIMENSIONAL CUTTING PROBLEM

7.0 A STAGED APPROACH TO THE FURNITURE MANUFACTURERS 2DC PROBLEM

As we have previously mentioned a solution approach based on the concept of optimality, where optimality is firmly based on the single decision criterion of waste levels alone is inappropriate. In practise we have found that manual heuristic solution procedures, which treat the 2dc problem as having multiple goals fair much better and are more readily accepted and used by the Planners than waste optimal computer solutions. The approach, which we now detail is therefore based upon the multi-decision criteria that we have previously outlined in chapter six. The approach consists of the following four stages:

STAGE ONE

** An inter-active User Defined pattern generator ; This part of the programme can be discounted by the Planner if required.

STAGE TWO

** Lexico-graphic sort of the stock and panel order sizes.

** Selection of Head cut candidates.

** Select primary widths for inclusion on j'th stock board: The routine used is based upon a dynamic incremental width threshold recursion, which controls the number of primary widths actually considered.

STAGE THREE

** Generation of length strip combinations for widths (wi) previously selected in stage two.

** Evaluation of length strip combinations : Four decision criteria are used in this strip evaluation procedure, namely:

- waste costs;
- diversity reward;
- panel closure reward;
- open order penalty.

** The selection of the length strip patterns for each width group for consideration by stage four is based upon a computed figure of merit.

STAGE FOUR

** Using n strips, for each W(i) width group, obtained from stage two, cutting patterns are generated and as such Stage Four is similar to stage three, namely

** The evaluation and selection of cutting patterns are based on the following five decision criteria:

- waste penalty;
- diversity reward;
- panel closure reward;
- open order panelty for panels;
- reward for panel appearance on cutting patterns.

** Once a cutting pattern has been accepted the programme then decrements and up-dates the cutting order list.

** Return to stage two and repeat until the panel order set is completed.

Diagramatically this four stage approach can be represented as illustrated in figure 20.0.

Before these four stages are detailed further we add the following paragraph which details some of the problems that arose and the solutions that were adopted during the model building phase.

The following two major problems arose when adopting a modelling approach which requires that specific characteristics of the problem are assigning values and the selection of what is best, is computed by a figure of merit: in effect the kernel of our proposed solution approach.

Firstly, the process of measurement will be based on complex mathematical equations which do not relate to the actual problem and which sooner or later become one of the central issues of the model.

And secondly, by computing a single measurement of acceptability, the decision process becomes about locating the highest or lowest number from within a list of numbers. The result being that the real decision problem is likely to be further distanced from reality.

To overcome these two weaknesses the model that we propose has been based upon detailed analysis and understanding of how the actual decision problem is formulated and processed by Planners. This has resulted in the situation that the mathematical equations, where used, are simple; reflect the decision problem without ambiguity; and offer the Planner maximum control and direction over the total problem domain and hence the Planner is better able to direct his solution procedure. For example, as the following details of the model structure indicate our proposed solution procedure deals with the trade-offs between the decision goals of waste minimisation; volume throughput; low number of cutting patterns and low panel spread. This new approach enables the Planner to specify the exact goal to be maximised at each level within the pattern generation procedure. If the current goal direction is required to be modified, then this is easily achieved via the inter-active screen based routines provided in the system.

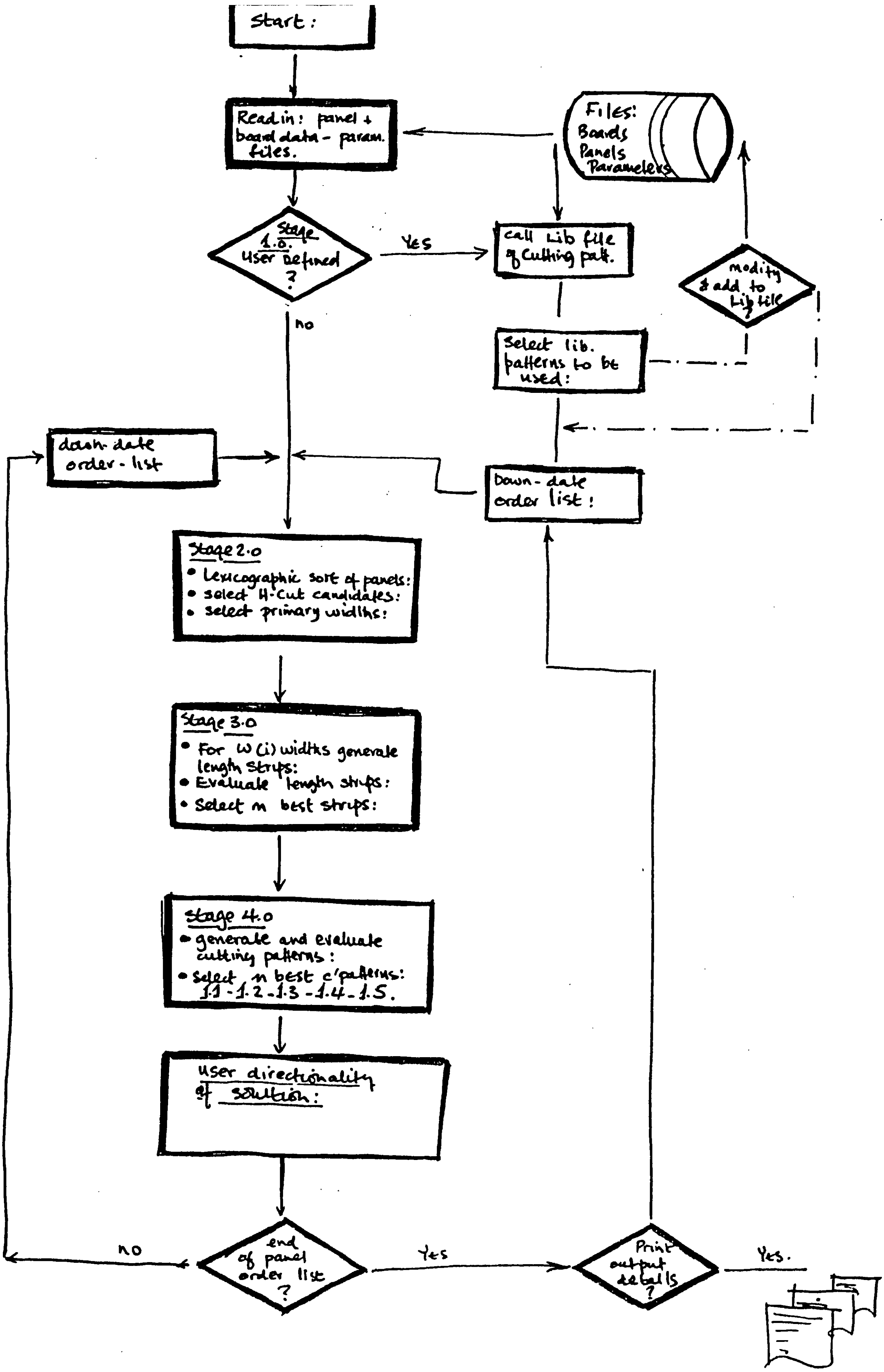


FIGURE 20.0 BASIC ALGORITHM

THE SOLUTION PROCEDURE DETAILED

7.1 STAGE ONE : User Defined Cutting Pattern Generator

It became evident from our research that Planners stored, at a sub-conscious level, sets of good cutting patterns: by good we mean patterns which have; acceptable waste levels; high panel order closures; and low or high open order quantities. Furthermore, when presented with an order list which contained known panel sizes - ie. panel sizes related to their own furniture - that required cutting patterns to be generated their initial action was to scan the panel order list in an attempt to match orders (panel types) with their acquired library file of good cutting patterns. In this pre-decision processing stage, as we have previously mentioned, small yet significant changes would take place to the order list so that some of the Planners patterns could be used. eg. extras would be added to the order list; panel types not initially included in the order list would be added.

In analysing these good cutting patterns it was possible to identify the following characteristics:

1. The cutting patterns were not optimal from a wastage criterion;

2. There were generally between three to five different panels on one cutting pattern;

3. The cutting patterns often closed two and occasionally three panel orders;

4. The remaining open orders, resulting from each cutting pattern, was either very low and hence could often be obtained from adopting a planning strategy; ie. closing a panel order prior to completion of the order quantity being filled, or was very high and as such could still be treated as a primary order candidate. In addition and more importantly Planners, albeit sub-consciously, traded savings in waste for a reduction in the number of cutting patterns: points three and four above effectively supporting such a trade-off.

This pattern matching first stage then goes some of the way in explaining why manual approaches result in less cutting patterns, with slightly higher wastage levels, than computer generated solutions. Quite simply, the objective function at the initial stage is to select cutting patterns that close a high proportion of the order list and which have an acceptable level of waste. Subsequent iterations will have less combinations that will satisfy these two goals and hence wastage levels will inevitably become the dominant goal. The final decision on the acceptability or otherwise of the cutting pattern set then unfolds through a process of practical knowledge about the panel orders combined with a series of heuristics which enable the Planner to trade-off the numerous competing decision goals. This latter phase being based on an understanding of how the solutions will be implemented in practise.

7.1.1. The User Defined Programme

Having identified the User Defined Approach, it seemed correct that the first stage of our solution should have a user defined routine, so that the Planner could define his good cutting pattern set and store, on disc, for later use, if required. This sub-programme is now described:

The User Defined Programme is a sub-programme which can be selected via the systems main menu. The programme provides the Planner with the following facilities:

* Set up of new cutting pattern:
* Display cutting pattern;
* Print cutting pattern;
* Amend cutting pattern;

Each of these options is structured in a user friendly mode and is provided with an error protection/support overlay. For example, the input dialogue for the setting up of a new cutting pattern is:

1. The programme clears the current menu screen and prompts the User for the following information:

(a) Library file number allocation for this pattern ?

(b) The board size (length x width) that is to be used ?

These details, once input remain on the screen as a memory aide for the User during the pattern input stage.

2. The following header is now screened, with the screen cursor positioned at the junction of the first column/row.

LIBRARY FILE PATTERN NO. 12345/1234

BOARD SIZE: 4500 x 2500 x 15mm

Strip No.	Panel Length	Sizes Width	Nested L:L	Head cut	No./Strip
99	9999	9999	y/n	y/n	99
99	9999	9999	y/n	y/n	99

Input Details Required from the User are:

(a) STRIP NUMBER: Each different strip width on the cutting pattern is required to be allocated a reference number which is calculated by simply adding a one (1) to the previous different strip width.

(b) PANEL DIMENSIONS: The length and width of the panels are input via the keyboard. Note that the saw kerf and the trip allowances, where applicable are taken directly from the parameter file

(c) NESTED L:L This input relates to the orientation of the panel length to the board length. If Y(es) is input then the panel length will be nested parallel to the board length. If N(o) is input then the panels width is nexted to the boards length.

(d) HEAD CUT: A Y(es) input indicates to the programme that a head cut pattern is required. The inputs are carried out in the normal way with the programme handling the pattern generation, see worked example.

(e) NUMBER per STRIP: The User is required to input the number of panels, defined by the current rows length and width input details, that are to be allocated to this strip width.

(***) ERROR MESSAGES. If the inputs are correct, ie. the summation of the PL* No./strip < = to the current board length then the input details are accepted and passed to the drawing part of the programme for calculation and storage on the disc. If these inputs are incorrect, then an error message is screened on the right hand side of the offending input row.

3. After the data for each column has been input, the screen cursor moves, in turn, across the row, column by column, until the end of the row. Movement to the next row is simply effected by depressing the carriage return key on the keyboard.

4. These instruction steps are continued for the number of width strips that are required for the current cutting pattern. Note that the programme checks the correct panel width/board summation for input

error and displays a corresponding error message.

7.2 STAGE TWO : INITIAL SORT AND SELECTION PROCEDURES

1. Sort stock boards by width and by length, within width. The number of stock boards to be used for each optimisation is defined in the programme by a parameter.

2. The programme sorts, in decending order, by outstanding order volume, the set of strip widths, W(1),W(2),W(3)......W(m), where W(m) defines the total number of different widths that are required to be considered by the algorithm. In addition, there is a special routine in the sort procedure which ensures that large panel sizes, which have only small order requirements, do not necessarily end up at the bottom of their respective groups.

3. The selection of panels, from the ordered list, as Head cut candidates is achieved from the following procedure:

Parameters Required:

(a) Minimum width of head cut allowed ....(H_{min})

(b) Maximum width of head cut allowed ....(H_{max})

(c) Preferred run length of pattern ....(R)

(d) Threshold for width usage of stock board ...(T) these parameters are presented in schematic form in figure 21.0

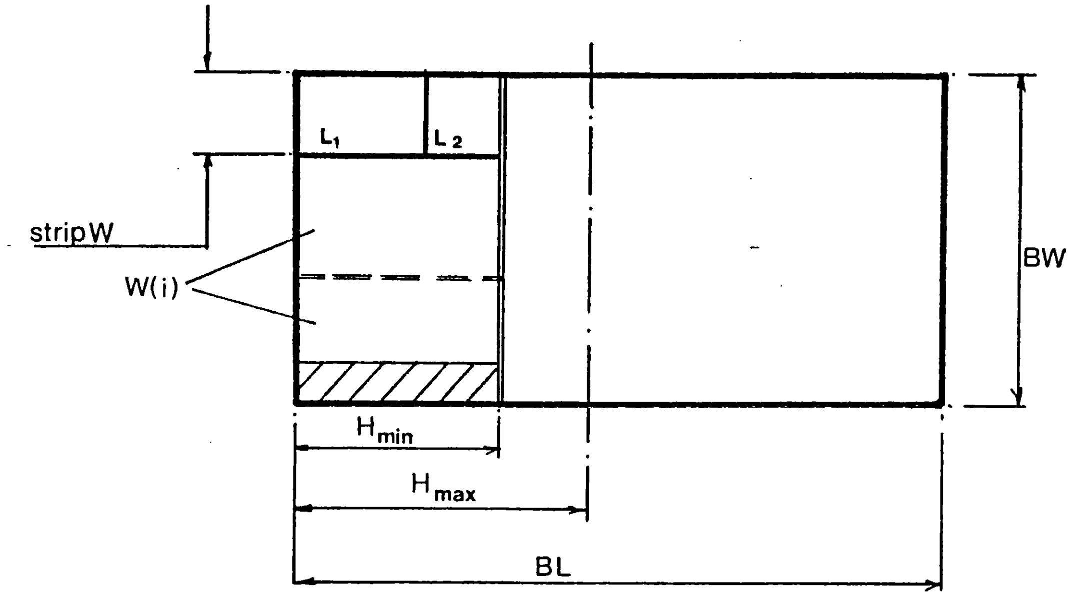


FIGURE 21.0 SCHEMATIC REPRESENTATION OF HEAD-CUT

We continue as:

(a) For each panel in order set compute for acceptance as Head cut candidate, re parameters HC_{min} and HC_{max} - ie.

for acceptance N1 panels of length IL1, N2 panels of length IL2 ... Nk of panels of length IL k, each of width W(i) must satisfy

BL - Sum (N1*IL1 + N2*IL2 + Nk*ILk) >= Hcut;<=Hcut ..(1)

(b) The next stage in selecting head cut panel candidates is achieved by the introduction of a board width usage threshold criteria. Only Panels that satisfy this threshold parameter are considered further:

For each panel width W(i) compute board width usage;

[BW - CBW / W(i)] * W(i) < - TPV ...... (2)

Given that TPV is the User supplied width threshold parameter.

(c) The final procedure in selecting suitable Head cut candidates is based on computing the actual run length of the cutting pattern, (ARL) and comparing the result with a User supplied parameter value, (PRL).

For example, from practical experience it is well known that Head cutting often decreases the wastage levels. This gain in material usage however, has to be balanced against the increased cost of performing the Head cutting operation and the ensuing loss of volume throughput, at the sawing operation. Hence Head cutting patterns are only considered by Planners if the savings in material costs are greater than the additional machining and labour costs associated with that pattern. These additional costs however are not considered directly by the Planner. In practise we find that the planner uses the heuristic of cutting pattern run length to decide on the suitability or otherwise of the head cutting pattern. Hence within our proposed solution method the Planner is able to specify, via a user defined parameter, the minimum run length that is required on a head cut pattern, ie:

Having calculated the number of panels of type p(i), occuring in the head part of the board, then the cutting pattern run length, RL can be calculated from;

$$RL - OSQR / SPHC \quad \text{where } RL >= PRL_{min} \qquad \ldots\ldots (3)$$

where OSQR is the outstanding quantity of panel type p(i) that is required and SPHC is the sum of panels of type p(i) contained in the head cut portion of the current cutting pattern.

Only if RL is greater than equal to the User supplied minimum pattern run length, PRL, will the pattern be included for consideration at subsequent stages within the algorithm. ie. A new board is calculated from (BL - HC dimension) and the resultant board size and the fixed quantity is added to the current board stock file to be treated as a normal board.

The final procedure in stage two is the selection of primary panel widths for inclusion on to the j'th stock board.

Given a set of widths, W(1),W(2),W(3)...W(m), the inclusion of widths, W(1),W(2),W(3)...W(m), in a cutting pattern can be represented by a vector,D, where D = (d(1), d(2), d(3).............d(m)).

ie. D(i) denotes the number of appearances of width W(i) in a cutting pattern and is a User supplied parameter.

Hence a cutting pattern is considered feasible under the following two conditions:

(a) Sum W(i),D(i) < = BW, where BW is the select stock board width.

(b) BW - Sum W(i), D(i)< min W(i), ie. the remaining strip width must be smaller than the smallest panel width in the current order requirement list.

7.2.1 Board width Calculation:

The board width usage for the j'th stock board can be caluclated from the following

W = Sum (W (i) * D (i)) / BW .... (4)

As an aid in selecting suitable stock board sizes from the initial stock set we introduce a width usage threshold parameter W max. If the width usage, W of the j'th stock board is less than the value of W max then the board size is rejected for further consideration at this initial stage. Given that the W max threshold parameter might well be set too low by the Planner and hence reduce the feasible region of combinations, the programme dynamically generates a suitable number of initial width strip candidates, irrespective of how low W max is set.

The board usage for all cutting patterns that successfully pass the W max threshold test is calculated from:

Sum (panel areas) * 100 / board area ..... (5)

7.3 STAGE THREE : GENERATION AND EVALUATION OF LENGTH STRIPS

Suppose N1 panels of IL1, N2 panels of IL2.....Nk panels of ILk , each of width W can be fitted end to end onto a strip of length IL and width W, (as shown in figure 22.0), then the value of this strip configuration, or pattern vector, can be determined by summing the following four components, namely:

(a) Linear usage of strip length.

(b) Diversity factor: ie. where different panel lengths of W(i) are included in one strip. Such pattern strips will have higher pattern run lengths than would otherwise have been the case if the same panel lengths of W(i) were included in the strip.

(c) Closure reward for strip that contain panels that have been previously opened.

(d) Penalty to discourage panel p(i) appearing on too many strip types unclosed.

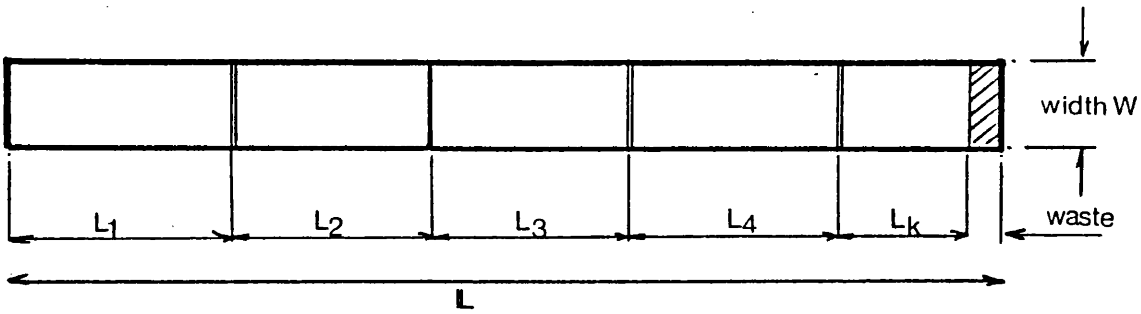


FIGURE 22.0 DIAGRAMATIC REPRESENTATION OF STRIP PATTERN

These four components that go to make up this third stage of the algorithm are now fully detailed.

7.3.1 Linear Usage of Strip Length:

The first component of the evaluation procedure can be simply represented by the percentage of linear usage of the strips length, L. Mathematically this can be formulated as:

100 * (N1 * IL1 + N2 * IL2 + ... Nk * ILk) / IL ......(6)

7.3.2 Strip Diversity Factor:

The value of a strip pattern is enhanced if a greater number of different panel types are included. In general, this will result in longer pattern run lengths of a particular strip pattern and a corresponding reduction in costs due to the reduction in pattern changes and the associated lost time that is experienced in practise. The diversity factor, which is the second component of our proposed value function is:

$$P_{div} *(K(n-i)) \qquad \text{........(7)}$$

where P_{div} represent a trade-off value for panel diversity: waste.

and K is the number of different panel types in strip S.

Note: K is further defined by a User supplied parameter.

7.3.3 Closure Reward for Panels in Strip N:

This value function is provided so that current strip combinations which have previously opened panel types on and which are reaching their maximum appearance limit; a User supplied parameter that is used in the evaluation stage of the algorithm - are selected in preference to strip types which have greater length utilisation. The equation that is used is as follows:

$$CR = P.closure * Sqr \quad \frac{(\ 1 + \text{no. of appear.})}{(\ \text{max no. of appear. permitted})} \quad \ldots(8)$$

where P.closure and maximum number of appearances permitted are User supplied values.

It should be noted that within the programme the diversity reward and the reward for closure act in a complimentary manner to determine the most appropriate strip patterns that provide a balance between the competing objectives.

7.3.4 Penalty for Open Panel Orders in Strip N:

One of the major criticisms directed towards generated trim problem solutions is their inability to contain the panel order p(i) to only a few appearances on the cutting patterns. Hence the forth component of our value function introduces a paramaterised linear piece-wise mathematical function which takes account and controls the spread of panel p(i) appearing on too many cutting patterns. The appearances of p(i) are controlled by the following:

Let OS(i), (i=1.....k) be the outstanding requirement for panels of each type T(j), appearing in a given cutting pattern. The pattern run length can be formulated from the following integer-expression, rounded up, to determine the pattern run quantity:

$$r = \min \langle(\overline{os}(i) + \overline{os}(i)-1) / \overline{os}(i)\rangle \qquad ......(9)$$

where $\overline{os}$ is the current outstanding panel requirement.
OS is the original panel order requirement.
and R is the calculated pattern run length.

If this is achieved for the j'th panel type, then the j'th panel type is considered closed.

A penalty is attached to panel types T(j) (j=1.....k) which remain open, based on the proportion, pi, of the outstanding requirement:

$$pi = r * \overline{os}(i) / OS(i) \qquad ......(10)$$

If pi> = 1 then zero penalty is incurred as the pi'th panel is closed.

If pi<1, the panelty for open or outstanding orders, os, for panel type T(j) is proportional to the following linear piece-wise function:

$$F(pi) = (1 + M *(pi-0.5))/4 \quad \text{if } pi >= 0.5 \quad ...(11)$$
$$(1 + H *(0.5-pi))/4 \quad \text{if } pi > 0.5 \quad ...(12)$$

where M and H are integers between 1 and 10.

As indicated in Figure 23.0 the linear piece-wise function has the initial properties that F(0) = 0.75

F(0.5)= 0.25 and F(1)=1. This function is designed to discourage either short pattern run quantities or pattern run quantities which would result in a small number of panels of type T(j) being still outstanding. (Note the values of M and H are parameterised and can be amended and controlled by the Planner to reflect his own preferences).

The total penalty for open orders, in the strip, can be calculated by:

$$P(open) = P_{op} * \text{sum } F(pi) \qquad .....(13)$$

where P_{op} is a parameter (value) supplied by the Planner, which reflects his preferred trade-off between the goals of open orders and waste.

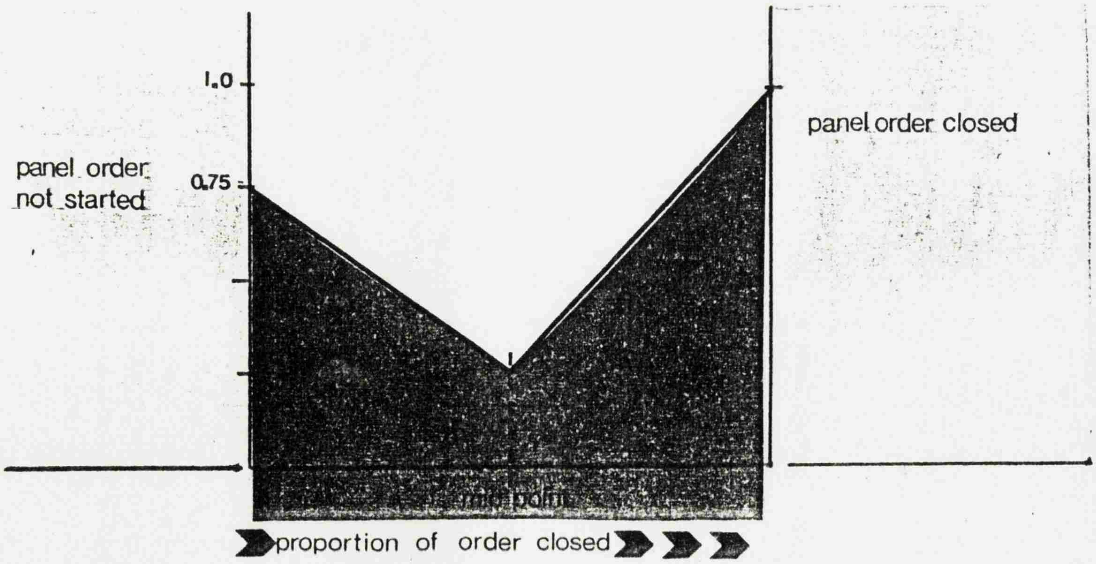


FIGURE 23.0 GRAPH OF PENALTY FOR OPEN ORDERS

7.4 STAGE FOUR : GENERATION AND EVALUATION OF CUTTING PATTERNS:

The fourth stage of our proposed algorithm is the generation and evaluation of cutting patterns. Basically the generation phase is achieved by a special knapsack algorithm which utilises N strips from within the length strip memory to generate a feasible combination of cutting patterns. To enable these generated cutting patterns to be evaluated the following decision criteria are used:

(a) Width usage of board;

(b) Diversity factor relating to number of panel types on the cutting pattern.

(c) Closure reward relating to the number of panel orders closed on this cutting pattern.

(d) Penalty for open orders relating to cutting patterns that have high panel type diversity but which, as a consequence, leave too many panel orders open.

(e) Reward for panel appearance specifically added to ensure that the attribute of panel spread is directly included and controlled.

As can be seen, decision criteria (a) thru (d) are almost identical in format to the decision criteria used in stage three and hence are not further detailed. The decision criteria of (e) however is new and as such is now detailed:

7.4.1 Reward for Appearance of Panel P(i) on cutting pattern:

The Planner is able to supply a value to A_{max} which is a parameter which indicates the maximum number of board patterns across which an individual panel type, p(j) may be spread. This component is included in our value function to reduce the handling and storage difficulties of partially completed orders at the outfeed position of the sawing operation. Relating to this attribute of panel appearance is the incentive to include and in fact close those panel types, p(j) which have already appeared on one or more previous cutting patterns.

In the assessment of a figure of merit for a cutting pattern vector, the closure of panel types, p(j) are actively encouraged by the following equation:

$$R(\text{appearance}) = Z * \text{sqr}\ ((1 + A_{max}) / A_{max}) \qquad ....(14)$$

ie. an additive reward for each panel type p(j) that is closed on this cutting pattern vector set.

where A_{max} is the number of previous appearances of panel type T(j), ie. the number of cutting patterns already generated which contain the j'th panel type.

and Z is a User supplied parameter initially set at 3.

Additional notes on (e)

The quadratic nature of this incentive, as shown by Figure 24.0 reflects the increased urgency, to the Planner, of closing panel types which are already nearing the panel spread limit. (a parameter set by the Planner). The function has been designed to have a value between 0 and 3, prior to scaling by the User supplied parameter for open orders, P_{op}. This scaling is commensurate with the given F(pi) values and the range takes into account the situation that is so often found in practise, ie. that Planners are prepared to trade up to 3% in the level of waste if and only if significant advantages result in one or more of the other decision goal areas.

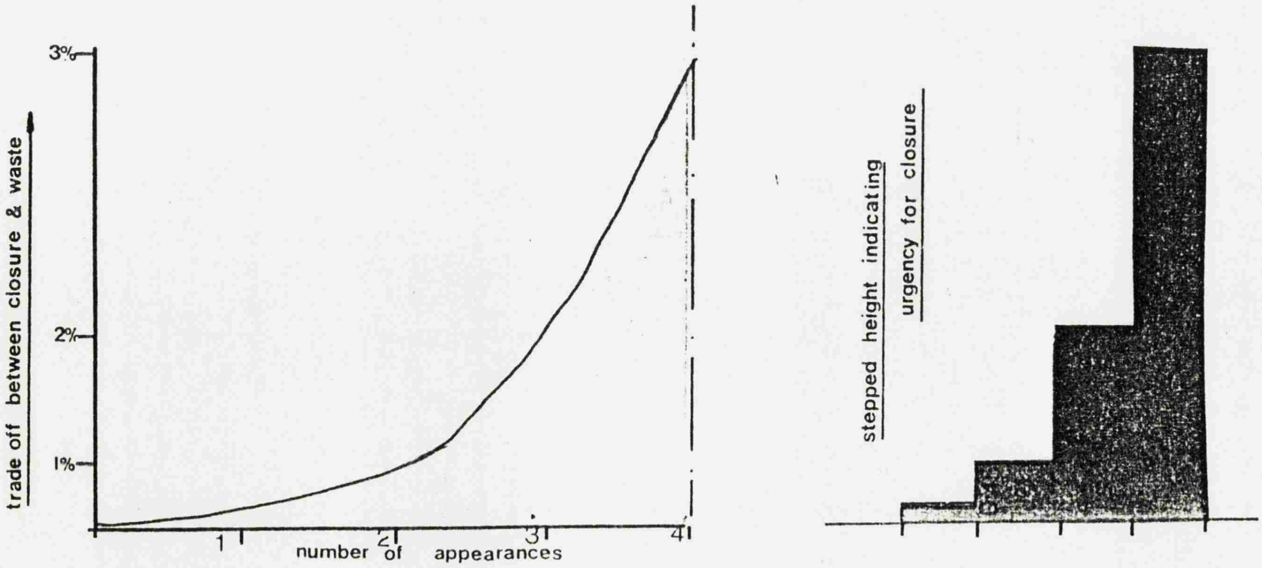


FIGURE 24.0 QUADRATIC FUNCTION REFLECTING URGENCY FOR PANEL ORDER CLOSURE

7.5 THE PLANNERS PREFERENCE SYSTEM AND THE SETTING OF PARAMETERS

It is tempting to suggest that the goals and their respective consequences as previously detailed in chapter six, can be formulated into a set of numerical scales. That presupposes, however, that the Planner can fully identify and describe his goal set in this way. As we have found, Planners do not think in such rational, numerical value terms. In addition determining cutting pattern combinations is a difficult and complex task and not all the consequences of the inter-related nature of the problem are easily formulated into scales of numerical values In many instances the decisions made by the Planners relate to notions of cutting pattern acceptability, rather than numerical values. This only increases the difficulty of eliciting their numerical systems of preferences.

Where it is difficult to relate nominal and numerical attributes, suggestions in the literature advocate that the problem be structured using the concept of trade offs. For example, in the 2dcp this could be achieved by considering the change in waste costs that would be required for a given change, in say the reduction in the number of cutting patterns, ie. the notion of trade-offs between differing sets of cutting patterns which produce the same set of panels. However, in practise it is not that simple. In our research we have found that Planners preferences and the trade offs upper and lower bounds, tend to change given certain circumstances. For example, the starting goal is just as likely to be the minimisation of the number of cutting patterns as the minimisation of waste. This preference for a low number of cutting patterns may be modified; even discarded, after the generation of the first few cutting pattern levels. The explanation for this simply being that the possibility of cutting patterns with high panel order closures existing is greatest at the start point, not part way through the pattern generation routine. Given that the Planner has, in these initial few cutting patterns, sacrificed potential savings in material costs for high panel order closures per cutting pattern, then the over-riding objective would now become one of waste minimisation. This would then require that a new set of preferences, centred around the waste minimisation objective be adopted.

7.5.1 Directionality Within the Problem Solution:

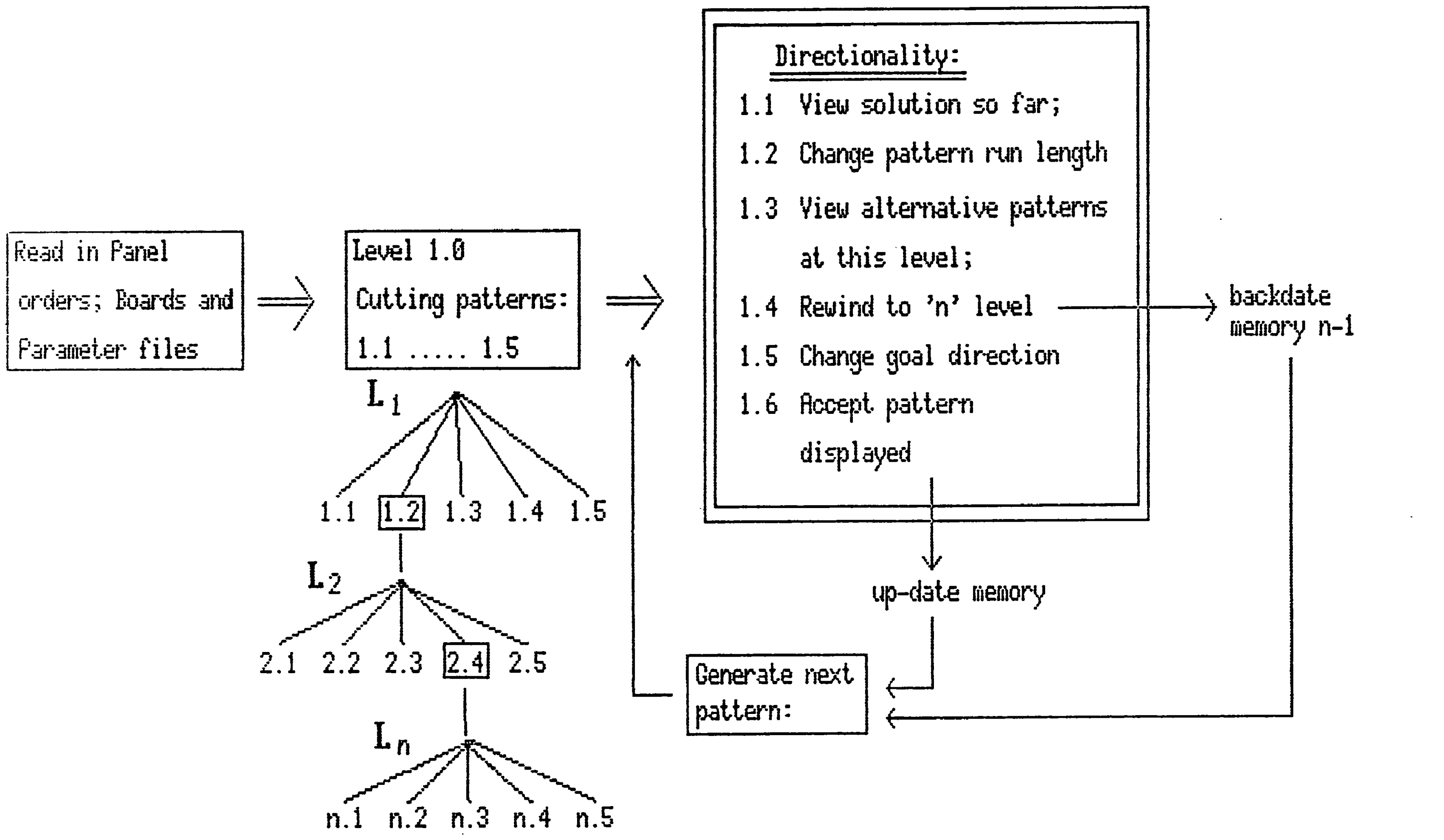
Planners, then, do not use just one set of order preference values in sorting through their cutting problem, but many. More importantly, the ordering of these preferences and the level and activity of trade offs between them tend to change, dependent upon the actual position that the Planner perceives himself to be in, ie. if there is pressure from the Production Manager for increased volume, due to high product demand, then the waste objective might very well be modified for an increase in volume throughput. Thus, although the concept of simple preferences and trade-offs between two or three alternatives is theoretically easy to handle, in many practical cases, as the 2dcp indicates, this is likely to be unrepresentative of the actual decision situation faced by the Planner.

In practice we find that Planners require to be able to direct the problem solution. ie. if volume is the current primary goal then the solution approach has to rank the other consequences in relation to this goal and then determine the solution. Often only part of the proposed solution is acceptable and hence the offending solutions are required to be re-calculated with the initial primary goal being ranked lower. In the 2dcp then, the manual problem solution is derived from successive iterations. Each iteration imparting additional information across the Planner's complete goal structure. The proposed solution base, and the additional information, ie. the cutting pattern and the characteristics contained therein may or may not result in the Planner restructuring his current goal direction.

Given this situation, our approach in structuring the Planners preference system was to directly consider, at each iteration stage, within the algorithm the following goals:

* cutting pattern with highest yield;
* cutting pattern with highest panel order closures;
* cutting patterns with highest volume throughput;
* cutting pattern with minimum set up/handling problems;
* cutting pattern which minimises the total conversion costs.

The result being that for the first time the Planner is able to examine all the possible goals and their resultant consequences and trade-offs at each level within the problem. If the current goal direction has to be modified then this is easily achieved within the interactive screen based routines provided by the programme. Figure 25.0 gives an overview of our proposed goal/directionality approach.



Block Diagram of Cutting Algorithm

FIGURE 25.0

7.6 SUMMARY

Many of the previous approaches to trim problems have been structured in a mathematical programming framework with the necessity for the Planner to address and set numerous cost related parameters. For example one LP/DP based 2DC model has over one hundred and ten parameters that the User can change. These mathematical approaches are firmly based upon the belief that there is a single one point optimum set of cutting patterns. In reality however, there are so many differing issues which continually change within the problem, that the optimisation solution model is often inappropriate. It is against this backcloth that we have in this chapter suggested a modelling approach more akin to the concept of a decision aid. Our approach being based upon the belief that the modelling approach should be about supporting and assisting the Planner in sorting through and understanding the implications of his decision making process. Hence our approach in modelling the 2dcp has been based upon the following two corner stones:

(a) The first requirement was to help and assist the Planner to fully comprehend his cutting stock problem by understanding the many possible goal directions that are available at each pattern generation level.

(b) Secondly, the modelling approach and the programme structure facilitate and contribute to the formation and evolution of differing goal directions. Hence solution strategies that previously would have been passed over or not considered at all, can now be identified and evaluated in the cutting pattern selection procedure.

The pattern generation algorithm that we have detailed in this chapter has been coded in Pascal and runs on a range of 16-bit micro computers. The interactive structure of the programme results in a powerful decision planning tool which allows the Planner to balance the competing and conflicting operational goals of: waste minimization; volume throughput; containment of the panel being spread across too many cutting patterns, whilst automatically generating the cutting patterns in the best possible sequence.

Currently four companies use the proposed computer solution procedure. Although each company makes use of the programme in a different way, the feed back suggests that the proposed solution is a major step forward in computer generated cutting patterns. The major advance being that it provides a tool whereby the Planner is encouraged to fully explore the total inter-related issues within the 2 dc problem.

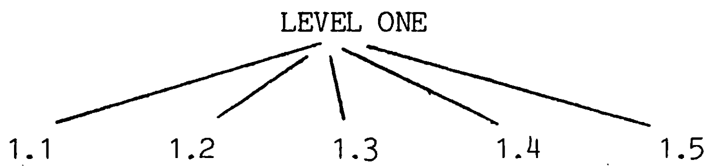
In the following chapter a detailed comparison between a linear programming approach and the proposed heuristic is undertaken.

CHAPTER EIGHT: COMPARISON OF PROPOSED METHOD WITH THE L.P. APPROACH.

8.0 LIMITATIONS IN THE LINEAR PROGRAMMING APPROACH.

The main limitations in the linear programming approach to the Furniture Manufacturer's 2 dc problem,relate to the exclusion of the technological components and the normative modelling approach which identifies waste minimization as being the primary objective. As we have identified, much of these limitations are a result of Operational Researchers failing to understand the significant difference between the various industries cutting problems. Although some of the cutting problem characteristics may be similar, specific industries will have different requirements. Hence stating that the linear programming technique does not work is incorrect: it is not the technique that is incorrect, rather the application of the technique to the problem.

The Planners in the Furniture Industry have shown by their non-usage of the L.P. approach, that a model which guaranties minimum wastage is not what they require. Their major requirement is for a decision tool which allows them to explore more effectively and efficiently their respective 2 dc problems. The approach that we propose meets this major requirement. ie. From the given panel and board details the programme generates a set of cutting patterns; 1.1 - to 1.5 at each generation level. e.g.



For each of these cutting patterns : 1.1 ... 1.5 a figure of merit and other relevant characteristics are displayed in turn on the V.D.U. screen for the Planner to evaluate. On completion of the evaluation the Planner is required to select one cutting pattern; say 1.2. The programme then decrements the order and board stock list. Pattern generation, User Evaluation, pattern selection and reduction of the panel/stock thereafter follow one another until the panel order requirement is satisfied, ie.

LEVEL 1

1.1 [1.2] 1.3 1.4 1.5

LEVEL 2

2.1 2.2 2.3 2.4 [2.5]

LEVEL 3

3.1 [3.2] 3.3 3.4 3.5

LEVEL 4

4.1 4.2 [4.3] 4.4 4.5

Incorporated into the programme is a REWIND and VIEW previous facility. The REWIND function is included due to the fact that decisions made at some previous level may prove to be incorrect. The REWIND function permits the Planner to return to that level and re compute the outcome at that level, re-select the cutting pattern and continue. The VIEW previous facility on the other hand allows the Planner to simply view the previously selected cutting pattern prior to making a decision at the current level.(see Figure25.0)

At this juncture the easiest method of illustrating the two different approaches to the 2 dc problem is through a set of worked examples.

For completeness the first worked example is given in the main body of this text, the remaining output results are to be found in appendix 3.

8.1 EXAMPLE 2.0

The following panel sizes and quantities were required to be cut from a board size 5020 x 2150:

*** PANEL SIZES	QTY	*** PANEL SIZES	QTY
1) 561 x 484	3600	2) 720 x 484	600
3) 1005 x 484	350	4) 682 x 484	630
5) 960 x 388	75	6) 960 x 378	150
7) 960 x 40	75		

Panels are rotatable; ie. have no grain direction and the user is able to accept up to ten per cent extra on any one panel type.

8.1.2 Comparison Procedure:

The panel and board details above were input, in turn to the two models. For each model, parameters were set to reflect the importance of wastage. In the linear programming model no other industrial characteristic parameters were available and as such the sole objective function was waste minimisation. In the proposed method the industrial characteristics of run length: panel closure and panel spread: and resultant waste levels, were set so that at each level a cross section of cutting patterns would be generated with an approximate three to four percent waste spread. For clarity and ease of understanding of these cutting patterns, the following vector notation is used:

[WIDTH] * [PANELS OF LENGTH La ; Lb ; Lc in WIDTH W(i)]

[W(i)] ni * (La(Wi)] ni; (Lb(Wi) ni; (Lc(Wi)] ... (15)

[W(j)] ni * (La(Wj)] ni; .... (16)

[W(n)] nm * [La(Wn)] nm; .... (17)

And the header abbreviations on the right hand side relate to:

f/m = Figure of merit for the calculated cutting pattern
w% = The waste percentage for this cutting pattern
rl = The run length (number of boards) required
c = The number of panel orders closed on this pattern
o = The number of open panels on this cutting pattern

8.2 HEURISTIC RESULTS

***** POPS ***** 180183 **** TEST **** ph.

Panel order sizes and quantitives required:

Line No.	Length	Width	Ident	Req'd
1.	561	484	1	3600
2.	720	484	2	600
3.	1005	484	3	350
4.	682	484	4	630
5.	960	388	5	75
6.	960	378	6	150
7.	960	402	7	75

Stock boards size available:

8.	5020	2150	8	200

PANEL ORDER / PLAN DEPENDENCE

	1	2	3	4
	Cutting Patterns			
1	*	*	3c	*
2	1c	*	*	*
3	*	*	3c	*
4	1c	*	*	*
5	*	2o	*	4c
6	*	2c	*	*
7	*	2c	*	*

SUMMARY

	M2	%P	%B
PANELS:	1676.1	100.0	91.9
EXTRAS:	16.24	1.0	0.9
BOARDS:	1823.9	108.8	100.0
WASTE:	147.8	8.8	8.1

TOTAL NUMBER OF BOARDS REQUIRED 169.

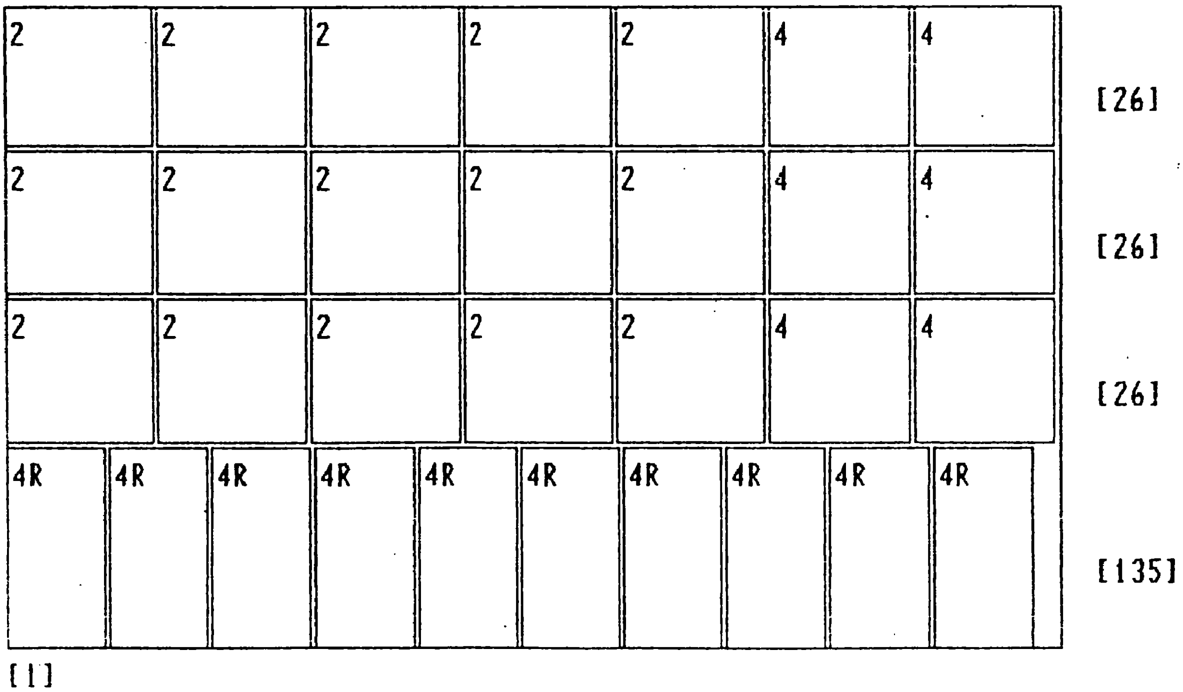
The total enumeration of the cutting patterns for this example are as follows:

LEVEL 1.0

Pattern	Cutting	f/m	w%	rl	c	o
1.1	[484] 3 * [720] 5 ; [682] 2 [682] 1 * [484] 10 ;	1013	2.63	40	2	0
1.2	[561] 2 * [484] 10 ; [1005] 1 * [484] 10 ;	877	4.61	35	1	1
1.3	[720] 2 * [484] 10 ; [682] 1 * [484] 10 ;	866	4.84	30	1	1
1.4	[720] 1 * [484] 10 ; [682] 2 * [484] 10 ;	823	6.54	32	1	1
1.5	[484] 2 * [720] 5 ; [561] 2 * [484] 10 ;	821	5.16	60	1	1

* Select cutting pattern 1.1 : Reasons: low wastage; closes two orders; good run length.

PATTERN NO. : 1.1. (1013)
BOARD SIZE : 5020 x 2150. NO. REQUIRED : 40. WASTE : 2.63 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
2.	B	720	484	600	600	0
4.	D	682	484	630	640	- 10

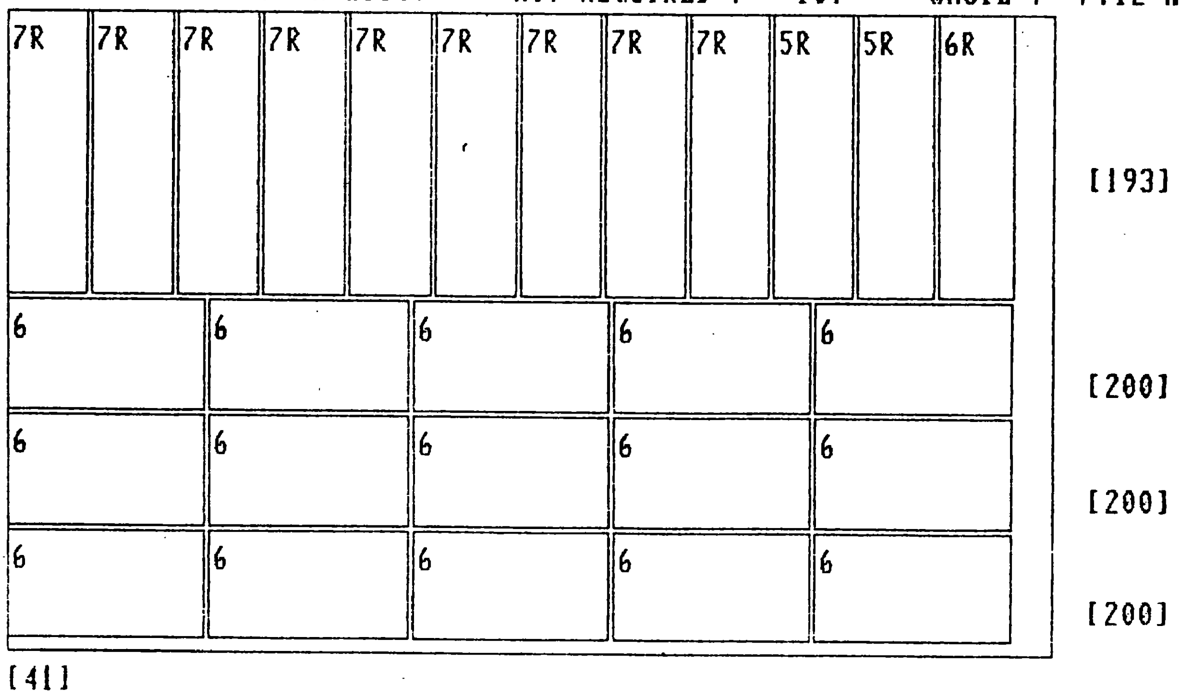
LEVEL 2

		f/m	w%	rl	c	o
2.1	[960] 1 * [420] 9 ; [388] 2 ; [378] 1	882	7.12	10	2	1
	[378] 3 * [960] 5 ;					
2.2	[561] 2 * [484] 10 ;					
	[1005] 1 * [484] 10 ;	887	4.61	35	1	1
2.3	[561] 3 * [484] 10 ;					
	[402] 1 * [960] 5 ;	818	6.64	18	1	1
2.4	[484] 1 * [1005] 1 ; [561] 7 ;					
	[561] 1 * [484] 10 ;					
	[1005] 1 * [484] 10 ;	816	7.56	32	1	1
2.5	[484] 2 * [1005] 1 ; [561] 7 ;					
	[378] 3 * [960] 5 ;	812	5.33	10	1	2

* Select cutting pattern 2.1: reasons; Acceptable wastage level - ie. below 8% ; closes two orders; although low run length, pattern accepted on strength of high order closure.

PATTERN NO. : 2.1. (882)

BOARD SIZE : 5020 x 2150. NO. REQUIRED : 10. WASTE : 7.12 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
7.	G	960	402	88	90	- 2
5.	E	960	388	72	20	52
6.	F	960	378	150	160	- 10

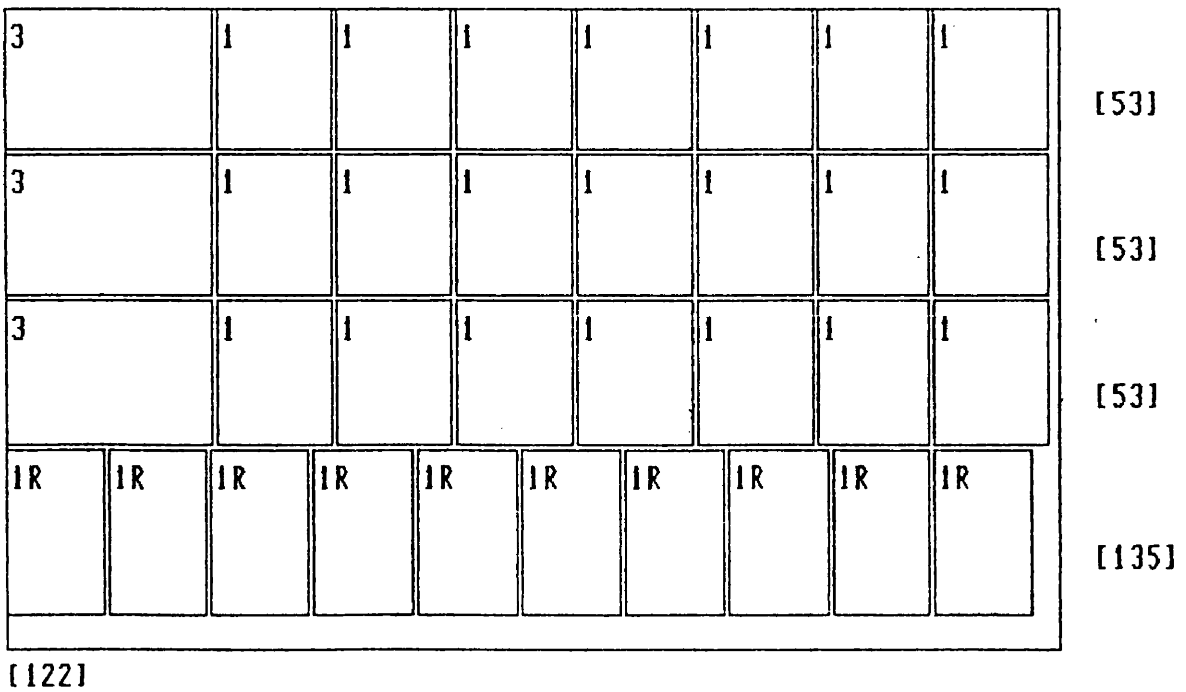
LEVEL 3

								f/m	w%	rl	c	o
3.1	[561]	2	*	[484]	10 ;							
	[960]	1	*	[388]	12 ;			963	8.27	5	1	1
3.2	[484]	3	*	[1005]	1 ;	[561] 7 ;						
	[561]	1	*	[484]	10 ;			881	8.49	117	2	0
3.3	[561]	2	*	[484]	10 ;							
	[1005]	1	*	[484]	10 ;			877	4.61	35	1	1
3.4	[484]	1	*	[561]	8 ;							
	[561]	1	*	[484]	10 ;							
	[960]	1	*	[388]	12 ;			866	13.3	5	1	1
3.5	[1005]	1	*	[484]	10 ;							
	[960]	1	*	[388]	12 ;			862	13.5	5	1	1

* Select pattern 3.2: Reason; Acceptable waste; high run length; closes two orders.

PATTERN NO. : 3.2. (881)

BOARD SIZE : 5020 x 2150. NO. REQUIRED : 117. WASTE : 8.49 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RO.
3.	C	1005	484	350	351	- 1
1.	A	561	484	3600	3627	- 27

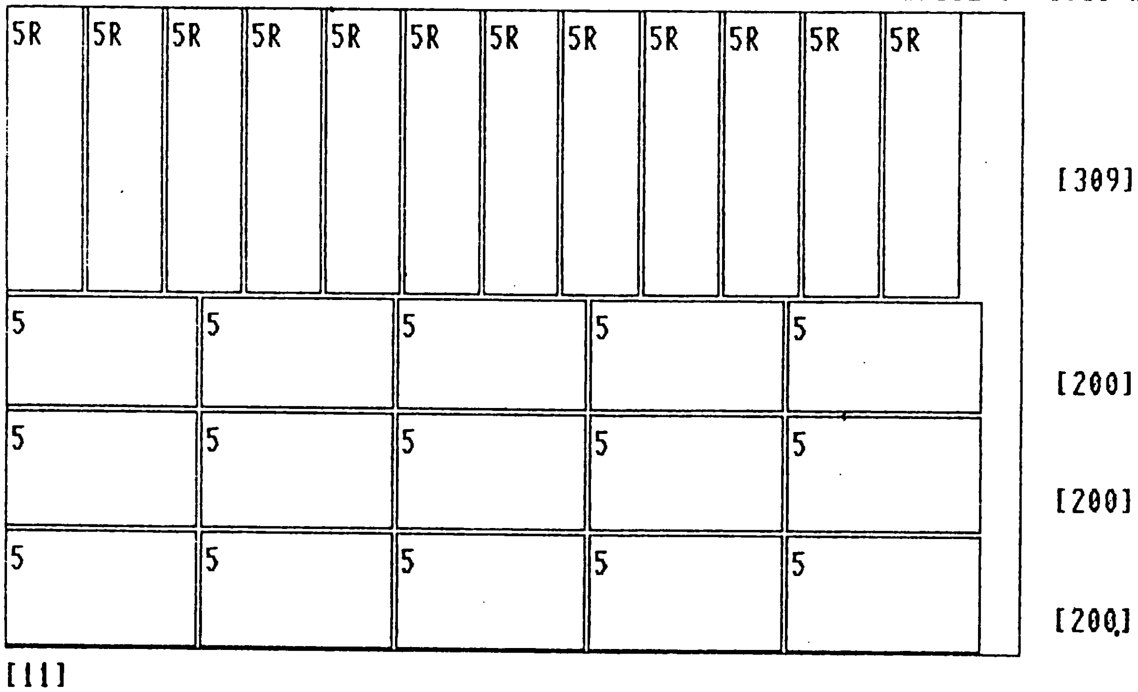
LEVEL 4

4.1	[960]	1	*	[388]	12	;								
	[388]	3	*	[960]	5	;		1006	6.8	2	1	0		

* Select pattern 4.1 Last panel required and is a singleton;
ie. single panel type only.

PATTERN NO. : 4.1. (1006)

BOARD SIZE : 5020 x 2150. NO. REQUIRED : 2. WASTE : 6.81 %



No.	Description / Code	Length	Width	No.Req.	No.Cut		RQ.
5.	E	960	388	72	54	-	2

8.3 LINEAR PROGRAMMING APPROACH

The linear programme system model used in this comparison test was the Opticut 2DC system. (35). The design of this system was taken directly from the delayed pattern generation techniques and linked knapsack solution advocated by Gilmore and Gomory. ie. an optimisation model where the objective function is to minimise the edge trim loss.

Once the parameters within the linear programme have been set and the data - panel dimensions, order quantities and stock availability - has been input the programme performs the necessary calculations and after a short period of time displays a SUMMARY of the results for acceptance by the Planner.

Re example 2.0 the following results were obtained from the linear programming model:

OPTICUT 180183 ****** TEST ******

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	561	484	3600	1	3610	10	980.2	4.90	
2	720	484	600	2	612	12	213.3	1.07	
3	1005	484	350	3	351	1	170.7	.85	
4	682	484	630	4	637	7	210.3	1.05	
5	960	388	75	5	80	5	29.8	.15	
6	960	378	150	6	168	18	61.0	.30	
7	960	402	75	7	75	0	28.9	.14	
8	5020	2150	9999	8	165	-9834	1780.8	8.90	

```
LINE/PLAN DEPENDENCE
1: 1  2  3  4  .  6  7
2: 1  2  .  .  .  6  .
3: .  .  3  .  .  .  .
4: .  2  .  4  .  .  .
5: .  .  .  .  .  .  7
6: .  .  .  .  5  .  .
7: .  .  .  .  .  6  .
8: 1  2  3  4  5  6  7
```

SUMMARY	M2	M3	%/P	%/B
PANELS	1676.1	8.38	100.0	94.1
EXTRA	18.1	.09	1.1	1.0
SHEETS	1780.8	8.90	106.3	100.0
WASTE	86.7	.43	5.2	4.9

SHEET USAGE
 165 + 5020 x 2150
LAYOUT (0-4) ? 4

OPTICUT 180183 ****** TEST ******

PLAN 501 5.4% SAW 1 SHEETS 23 * 5020 x 2150 x 5.0 248.2 M2 1.24 M3

```
:---------------------------------------------------------:
: 484.10   :     :     :     :     :     :     :     :   :X:(130)
: X561     :     :     :     :     :     :     :     :   :X:
:--.2----------------------------------------------------:X:
:     :    :     :     :     :     :     :     :     :   :X:
:     :    :     :     :     :     :     :     :     :   :X:
:     :    :     :     :     :     :     :     :     :   :X:
:---------------------------------------------------------:
: 561.5:     :      :     :     :720.3     :     :         : (15)
: X484 :     :      :     :     : X484     :     :         :
:--.2------------------------------.2---------------------:
:      :     :      :     :     :          :     :         :
:      :     :      :     :     :          :     :         :
:---------------------------------------------------------:
;                                                         :
:---------------------------------------------------------:
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	690	187.4	.94	
3	720	484	600	2	138	48.1	.24	

PLAN 502 4.5% SAW 1 SHEETS 13 * 5020 x 2150 x 5.0 140.3 M2 .70M3

```
:-----:-----------------------------------------------:
:561  : 484.9    :     :    :    :    :    :    :    :: (53)
: X484:  X682    :     :    :    :    :    :    :    ::
:--.4-:     :    :     :    :    :    :    :    :    ::
:     :-----------------------------------------------:
:     : 484.9    :     :    :    :    :    :    :    :: (53)
:-----:  X720    :     :    :    :    :    :    :    ::
:     :   *2     :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:     :----------------------------------------------::
:-----:     :    :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:-----:     :    :     :    :    :    :    :    :    ::
:XXXXX:-----------------------------------------------:
:-----:-----------------------------------------------:
 (194) (13)
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	52	14.1	.07	
2	720	484	600	2	234	81.5	.41	
4	682	484	630	4	117	38.6	.19	

OPTICUT 180183 ****** TEST ******

PLAN 503 4.3% SAW 1 SHEETS 39 * 5020 x 2150 x 5.0 420.9 M2 2.10 M3

```
:-----:-----------------------------------------------:
:561  : 484.9    :     :    :    :    :    :    :    :: (53)
: X484:  X561    :     :    :    :    :    :    :    ::
:--.4-:---.2-----------------------------------------::
:     :     :    :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:-----:     :    :     :    :    :    :    :    :    ::
:     :-----------------------------------------------:
:     : 484.9    :     :    :    :    :    :    :    :: (53)
:     :  X1005   :     :    :    :    :    :    :    ::
:-----:     :    :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:     :     :    :     :    :    :    :    :    :    ::
:-----:     :    :     :    :    :    :    :    :    ::
:XXXXX:-----------------------------------------------:
:-----:-----------------------------------------------:
 (194) (8)
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	858	233.0	1.16	
3	1005	484	350	3	351	170.7	.85	

```
OPTICUT 180183  ******  TEST  ******

PLAN 504  5.4% SAW 1 SHEETS 65 * 5020 x 2150 x 5.0  701.5 M2  3.51 M3

    :-------------------------------------------------------:
    :484.10      :     :    :    :    :    :    :    :   :X:( 130)
    : X561       :     :    :    :    :    :    :    :   :X:
    :--.2---------------------------------------------------:X:
    :     :      :     :    :    :    :    :    :    :   :X:
    :     :      :     :    :    :    :    :    :    :   :X:
    :     :      :     :    :    :    :    :    :    :   :X:
    :-------------------------------------------------------:
    :561.4 :      :     :    :682.4    :    :     :         : (8)
    : X484 :      :     :    : X484    :    :     :         :
    :--.2--------------------.2-----------------------------:
    :      :      :     :    :         :    :     :         :
    :      :      :     :    :         :    :     :         :
    :-------------------------------------------------------:
    :                                                       :
    :-------------------------------------------------------:
   (40)
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	1820	494.2	2.47	
4	682	484	630	4	520	171.6	.86	

```
OPTICUT 180183  ******  TEST ******

PLAN 505  6.2% SAW 1 SHEETS  6 * 5020 x 2050 x 5.0  64.8 M2  .32 M3

    :-------------------------------------------------------:
    :960.5       :           :           :        :      :X: (195)
    :-X378--------------------------------------------------:X:
    :  *3        :           :           :        :      :X:
    :            :           :           :        :      :X:
    :-------------------------------------------------------:X:
    :            :           :           :        :      :X:
    :            :           :           :        :      :X:
    :-------------------------------------------------------:
    ; 378.13 :     :     :    :     :     :     :    :  :: (41)
    : X960   :     :     :    :     :     :     :    :  ::
    :    :   :     :     :    :     :     :     :    :  ::
    :    :   :     :     :    :     :     :     :    :  ::
    :    :   :     :     :    :     :     :     :    :  ::
    :-------------------------------------------------------:
    :-------------------------------------------------------:
   (36)
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
6	960	378	150	6	168	61.0	.30	

OPTICUT 180183 ****** TEST ******

PLAN 506 5.6% SAW 1 SHEETS 15 * 5020 x 2150 x 5.0 161.9 M2 .81 M3

```
:---------------------------------------------------:
:960.5     :          :          :          :     :X: (195)
:-X402----------------------------------------------:
:484.10    :     :    :     :    :     :    :     :X: (130)
: X720     :     :    :     :    :     :    :     :X:
:     :    :     :    :     :    :     :    :     :X:
:     :    :     :    :     :    :     :    :     :X:
:---------------------------------------------------:
:561.5 :     :     :     :     :720.3    :    :     : (15)
: X484 :     :     :     :     : X484    :    :     :
:--.2--------------------------:--.2----------------:
:      :     :     :     :     :         :    :     :
:      :     :     :     :     :         :    :     :
:---------------------------------------------------:
:---------------------------------------------------:
 (40)
```

L/N	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	150	40.7	.20	
2	720	484	600	2	240	83.6	.42	
7	960	402	75	7	75	28.9	.14	

OPTICUT 180183 ****** TEST ******

PLAN 507 6.2% SAW 1 SHEETS 4 * 5020 x 2150 x 5.0 43.2 M2 .22 M3

```
:---------------------------------------------------:
:484.10   :    :    :    :    :    :    :    :    :X: (130)
: X561    :    :    :    :    :    :    :    :    :X:
:---------------------------------------------------:
:960.5    :         :         :         :         :X: (195)
:-X388--------------------------------------------:X:
:   .4    :         :         :         :         :X:
:         :         :         :         :         :X:
:-------------------------------------------------:X:
:         :         :         :         :         :X:
:         :         :         :         :         :X:
:-------------------------------------------------:X:
:         :         :         :         :         :X:
:---------------------------------------------------:
:                                                   :
:---------------------------------------------------:
 (12)
```

LEN	LENGTH	WIDTH	REQ	INDENT	CUT	M2	M3	DESCRIPTION
1	561	484	3600	1	40	10.9	.05	
5	860	388		5	80	29.8	.15	

8.4 COMPARISON OF THE TWO APPROACHES:EXAMPLE 2.0.

If waste minimisation were the objective function then clearly the linear programming solution would be preferred. Waste minimisation, however, as we have continually pointed out, is only one of the system variables that the Planner is required to consider in determining cutting patterns. The other significant variables are:

(a) Volume throughput;

(b) Number of cutting patterns to panel orders input;

(c) Panel spread;

When these variables are compared against the differing results for example 2.0 then the proposed solution, rather than the linear programming approach is preferred. ie.

(a) Volume throughput: The linear programming approach results in cutting patterns which have high pattern complexity, ie.

[il CP 503 and 504 require head cutting operations:

[ii] CP 506 is a triple staggered and hence requires additional time at the cross cutting operation.

In comparison, the proposed solution results in all single staggered cutting patterns; a very low level of pattern complexity.

The actual volume throughput for the two different solutions are as follows:

LINEAR PROGRAMMING APPROACH	PROPOSED SOLUTION
CP - Total time re'qd	CP - Total time re'qd
501 - 34.16	1.1 - 50.13
502 - 23.49 + 13.0 [h/cut]	2.1 - 13.10
503 - 62.49 + 39.0 [h/cut]	3.2 - 163.92
504 - 77.78	4.1 - 6.2
505 - 13.66	
506 - 27.34	
506 - 5.98	
4.94 hours: 1.69 m3/hr	3.89 hours: 2.15 m3/hr

ie. the proposed solution results in an increase of 21% in volume throughput.

(b) Number of cutting patterns to panel order ratio:

As is expected, the linear programming approach results in a 1:1 ratio of cutting patterns to actual order inputs. On the other hand the proposed solution register a 7:4 ratio. The main reason for this significant reduction of cutting patterns is that the Planner traded, at levels 2 and 3 increased panel order closure per cutting pattern rather than the objective of minimum waste.

(c) Panel spread: In the linear programming solution panel order 1 is spread across six cutting patterns in an effort to minimise the material usage. However, as can be seen from cutting pattern 3.2 (page 189) panel order 1 can be mixed with panel order 3 to give acceptable waste and a very high run length. In addition given that the resultant pattern is of a low pattern complexity level the volume throughput will also be high. These advantages have to be traded against an increase in the wastage levels for this panel order set: an increase of four boards or 3.6%

8.4.1 Extended Test Results:

When judged against the total decision goals that the Planner faces in reality, our proposed heuristic approach is far superior than the linear programming approach, as the following extended table of results from additional worked examples illustrates:

TABLE 2.0 : DETAILED COMPARISON OF THE PROPOSED METHOD VERSUS THE LINEAR PROGRAMMING MODEL.

iteria	No. of Orders	No. of c'patt		Diff		B'd area Used		Diff		Max No. apprearances for any one panel order		Diff
		LP	HM	LP	HM	LP	HM	LP	HM	LP	HM	LP
st No												
1	10	9	4	+5	0	922	922	0	0	7	3	+4
2	6	6	3	+3	0	328	360	0	+32	4	3	+1
3	11	11	4	+7	0	2024	2098	0	+74	9	3	+6
4	9	8	5	+3	0	938	938	0	0	5	3	+2
5	7	7	4	+3	0	1187	1198	0	+11	7	3	+4
6	10	9	4	+5	0	625	625	0	0	6	3	+3
ALS:	53	50	24	+26	-	6024	6141	-	117	-	-	-

Additional Notes:

1. Whilst the Linear programming method results in lower material usage, this has been obtained at the following expense.

(i) Requires fifty cutting patterns; twenty six more than our proposed method.

(ii) The spread of the panel orders is far too excessive. In practise the maximum spread is required to be contained to three or four. EG. see test three's results - one panel order appears on nine cutting patterns.

2. In comparison the proposed heuristic method used marginally more material; less than two percent, however, the number of cutting patterns were twenty six less than the LP method and the spread of panel orders was kept to the level of three.

8.5 SUMMARY:

Although the examples used in this comparison test contained few panel order sizes the results clearly indicate the main areas in which the normative linear programming approach fails. Quite simply, the Furniture Manufacturers 2DC problem is a multiple goal decision problem. Failure to treat the problem as such will inevitably result in solutions which although superior in waste minimisation do not reflect the real world decision which confronts the Planner. Whilst the solution that we propose may not have the mathematical elegance of the linear programming methods, it does reflect the actual decision problem and more importantly the solutions are more robust and are possible for the Planner to implement.

(In appendix A3 a detailed output is given of the new heuristic proposal. The output documents the total stages of the model . In addition, the detailed results from which Table 2.0 was derived is also documented).

CHAPTER NINE: SAW PURCHASE DECISION

9.0 ADDITIONAL CHALLENGES AND RESULTANT PROBLEMS

In Chapter Four we made mention of the fact that wastage levels are as likely to be constrained by the sawing methods employed, which mechanistically controls the level of cutting pattern complexity, rather than poorly conceived computer models of the 2dcp. Hence in this chapter the Saw Purchasing Decision that faces the furniture manufacturer is addressed.

As previously identified in Chapter One, the Furniture Industry, from its origins as a craft industry, has developed into two specific groupings each serving different markets and following different manufacturing philosophies, in an attempt to satisfy their respective customer groupings. This transformation has resulted in suitable technologies being developed, not only for the present day raw materials of: Chipboard; Flaxboard; Medium density fibre board and the like, but also in the development of specialised plant and machinery. These changes, combined with the following marketing factors of:

(a) the disproportionality between the demand for furniture products and the wood availability; coupled with,

(b) the need to supply products that were not only simpler to manufacture, but which also had a greater market appeal;

has resulted in a large proportion of the U.K. Furniture Industry adopting an engineering approach to the manufacture of furniture.

'The innovations of materials and machines, although offering certain cost and technological advantages, has also created new managerial decision making problems for Furniture Manufacturers. For example, the shift away from real wood towards board substrates was only possible due to the combination of advances in wood, adhesive and machinery technologies. However, whilst the new types of material solved the immediate problem of raw material availability, it also presented management with many additional challenges and problems: eg.

(a) the 2dcp - prior to the introduction of homogenous substrates being used the 2dcp did not exist in the furniture industries.
and

(b) Capital Investment decisions - with the high capital cost of sophisticated panel processing machinery; (an automatic saw can cost from £100,000 to £200,000) no longer then can machinery purchasing decisions be regarding as insignificant. It is this second managerial decision then that we address in this Chapter.

9.1 BACKGROUND TO THE SAW PURCHASE DECISION

It has been previously suggested, in Chapter Four, that one of the root causes of problems associated with the Furniture Manufacturers 2dcp is the sawing machinery that is used in the primary conversion operation. This suggestion is further supported when analysing the cognitive maps of Figures 7.0 and 8.0 / pages 67 and 70 respectively. The maps clearly show the inter-relationship and affect that the incorrect saw purchase decision has on the variables of volume; pattern complexity and profitability. What has to be remembered is that different saws and their design characteristics effectively control the level of pattern complexity that can be achieved at the cutting operation. Hence the decision on what saw is purchased can have a significant effect on the profitability of the enterprise. In practice however, we find at the analysis stage of the saw purchasing decision, the evaluation of the proposed saw purchase concentrates on global issues rather than specifically on how the saw design will effect the planning and sequencing of cutting patterns. These latter issues are rarely raised due to:

(a) Lack of product mix information available such that suitable analysis of pattern requirements; saw times, volume throughput, and potential wastage costs can be undertaken.

(b) Lack of understanding, by the Decision Makers concerned; the saw manufacturers and their agents (who are more interested in closing a sale than debating specific technical issues) and their furniture counterparts who tend to want to discuss everything at a global level;

(c) An overall belief that everything should be looked at in simple terms rather than recognising and hence tackling the complexity of the problem.

9.2 STATE OF THE ART

The above statements are not meant to imply that the Furniture Industry is devoid of thinkers, or that little time is spent in considering capital purchases. For example, significant analysis by Dr R Gowan and the introduction of a cut to size optimisation system in 1971 enlightened many Furniture Manufacturers. Further work by Gowan, in conjunction with Schelling; one of the leading automatic sawing machine companies - has added much to the state of the art, re the primary conversion process. The realisation, for example of the significance of pattern complexity on costs; material and machinery was identified, formulated and presented in a graphical format, as indicated in figure 26.0.

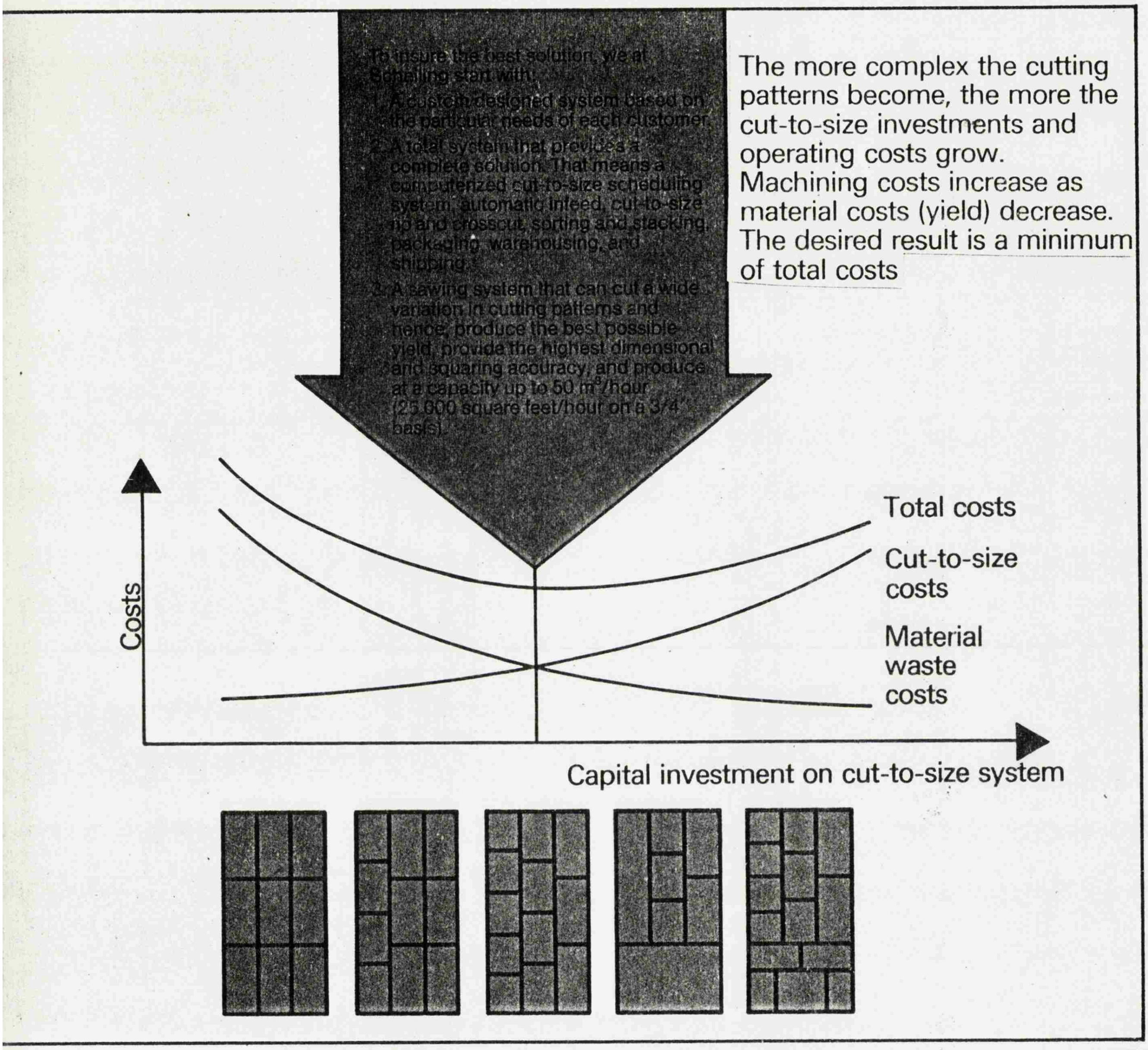


FIGURE 26.0 CAPITAL INVESTMENT DECISION ON SAW PURCHASE

The graph in Figure 26.0 however, does not tell the whole story. The variables are global rather than specific and only a general feeling can be achieved about how the variables interact. This then is the background to the Saw Purchasing Decision. It is not a simple problem and there is little or no published work available to assist the decision maker. The majority of the information residing with the specific saw manufacturers or their consultants, rather than with the end user group : The Furniture Mnaufacturer.

9.3 MACHINE SELECTION : CURRENT APPROACH

Often the problem of machine selection; in this case sawing machines is in part delegated by the Furniture Manufacturer to the machine company and/or their technical agent. Generally the following two questions are posed to Furniture Manufacturers.

The first question attempts to define, in some way, the Furniture Manufacturers budget for the intended acquisition.

The second, is concerned with the volume requirement that the Furniture Manufacturer requires from the new saw.

The answers given allow the saw manufacturers and their agents to manoeuvre between their model ranges of their saws and the various attachments available thereby balancing the Furniture Manufacturers budget so that it fits a specific saw type. This fitting of saws often results in the Furniture Manufacturer obtaining the maximum his budget can afford, rather than a sawing machine which matches his needs and circumstances. Hence the overall resultant is that neither party is totally satisfied: the Furniture Manufacturer feels that the saw doesn't quite match up to his expectations and the Machinery Supplier feels that some people are never, ever satisfied.

9.4 TECHNICAL DETAILS

At the technical level the following requirements can normally be obtained, either by detailed reading of the sales literature, or directly from the machine manufacturers:

* Accuracy level of specific materials that will be cut;
* Average volume requirement that can be expected;
* Maximum stack height that the saw will cut;
* Speed and feed rates of the saw and the pushers;
* Average loading and unloading times;
* Service and back-up support;

This listing is not exhaustive. However, it is an indication that some level, of minimum technical specification can be considered and set by the Furniture Manufacturers.

9.5 TWO VIEWPOINTS

Although a high proportion of the operational characteristics of the various sawing machines may be acquired from the technical literature, the fact remains that there are two viewpoints that have to be considered, namely the Furniture Manufacturers; the purchaser and the Saw Manufacturer; the supplier.

9.5.1 The Purchaser' s Viewpoint.

The purchaser normally sends out requests for quotations from numerous suppliers; say A to H, for example. The specification generally sets down the following requirements:

Operational specifications required from new saw:

- volume requirement;
- material to be cut;
- approximate price that is available for the saw;
- required delivery and installation timetable.

On receiving quotations from the suppliers, A to H the purchaser is in a position to evaluate their suggested solutions. This initial evaluation phase tends to be carried out by testing the suggested solutions against the following two decision criteria, namely, the operational minimum specification required from the saw and the constraints imposed by the financial budget. Diagramatically this can be represented as illustrated in Figure 27.0.

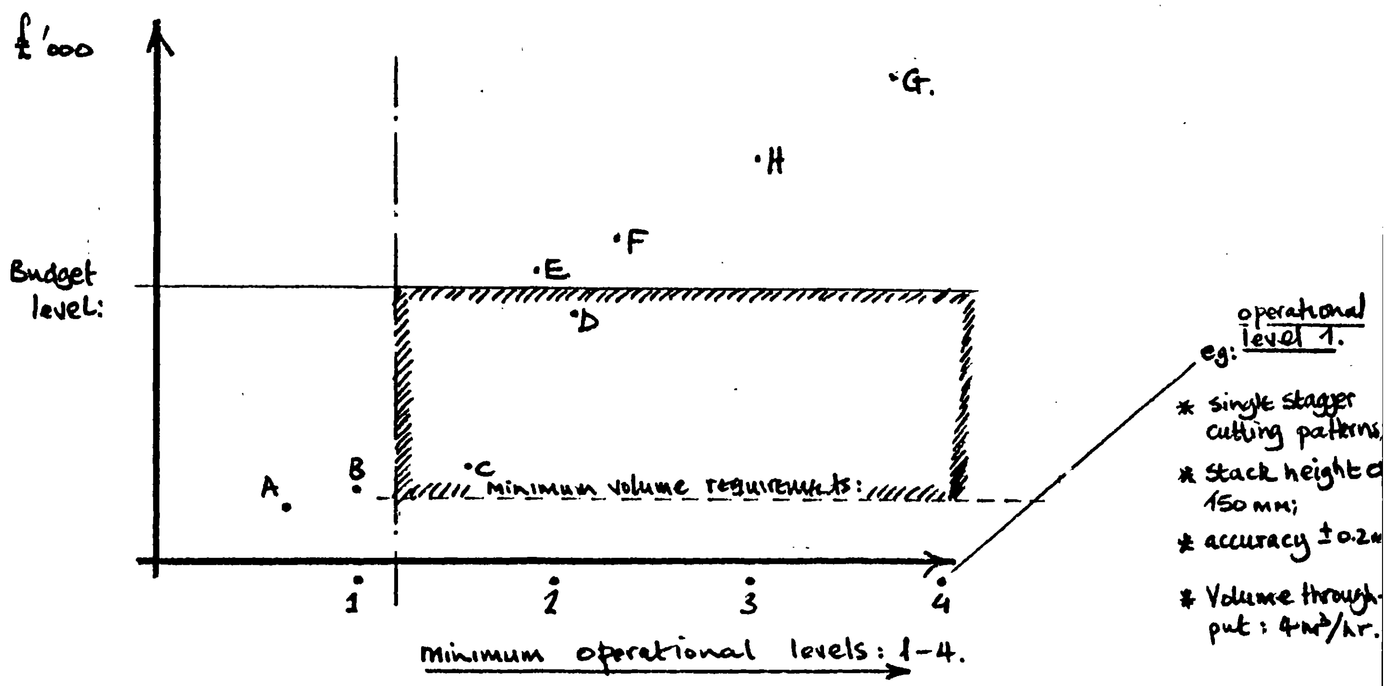


FIGURE 27.0 SAW PURCHASE EVALUATION

As can be seen from Figure 27.0 which pictorially illustrates the various options available to the decision maker, suppliers A and B can be discounted as they fail to meet the minimum operational specification required by the purchaser. Suppliers F, G, and H although meeting the minimum operational specification are too expensive. However, supplier F is close enough to be 'used' against suppliers D and E. Note that supplier C is too near the lower end of the volume requiremnt for serious consideration.

There are two basic alternative strategies for the purchaser to now consider; either accept supplier C, or secondly play supplier F against E in the hope of moving supplier F into the feasible region. Given these two alternatives, the purchaser nearly always opts for the play-off option. The two main reasons for this are:

(a) The political pressure for the purchaser to buy beneath his capital budget.

(b) The basic idealised belief, inherent within the industry, which actually believes you can get something for nothing - and you never do of course.

9.5.2 The Suppliers Viewpoint:

The suppliers basically know whether they have a reasonable chance of success or not, right from the start. This, in part, is due to:

(a) Extent of past business with the purchaser;

(b) The basic reluctance, by the purchaser, to change his current supplier. As pointed out by one Furniture Manufacturer ....

" to suddenly change from one machinery supplier to another requires a lot of justification internally"

Often suppliers A, B, C, and H know they are not in the running from the start and suppliers D and F know they are being used as pawns to manipulate supplier E. In turn supplier E also understands the situation and hence has the following three gaming strategies available:

(a) Add on, at the initial quotation stage, an inflated cost;

(b) Pare down, at the second stage, the technical specification; eg. reduce motor horsepower; cheapen up outfeed table conveyor; omit pushers and alignment devices.

(c) Re evaluate the purchasers sawing requirement based on arriving at a "better understanding". This latter approach nearly always results in the supplier carrying out (b) above.

9.5.3 The Final Sequel:

The final sequel allows for some "horse-trading", to take place and visits, for the prospective purchaser are also arranged to similar, but never exactly the same, installations. This seeing is believing approach generally appeals to the non-numerate, pragmatic Furniture Manufacturer and hence the sale is all but closed.

9.6 CRITIQUE

The previously described scenario is not so far removed from reality as might be imagined, in fact during the late seventies this was typical of how many machine purchasing decisions were made.

The major and most significant omissions in the current saw purchasing decision approach are that no detailed considerations are given to what actually will be cut; the product; the panel mix; the cutting patterns; the waste levels; the differential costs between sawing costs and waste costs. These variables and others are required to be brought into the evaluation procedure, such that the implications of the saw purchasing decision is fully understood by the Furniture Manufacturer. Certainly a much deeper and thorough analysis of these variables and their interaction is considered essential if the total minimum cost of the primary conversion operation is ever to be achieved. The requirement is for the Furniture Manufacturer to realise, as some do, that the purchase of a saw is far more than just a capital purchase decision. An incorrect saw purchase decision, as suggested in chapter four, pp. 99-100, can have very significant effects on subsequent operational decisions, especially in the area of cutting pattern generation and planning for the remainder of the Mill department. The best saw is by no means the cheapest, nor is it true that the most expensive saw is bound to be the best.

9.7 A SIMULATION APPROACH TO THE SAW PURCHASING DECISION

It is our contention that the saw purchasing decision facing the Furniture Manufacturer exhibits so many potential solution combinations that the most appropriate method of evaluation is simulation. In many cases the eventual solution adopted will be dependent upon the current and future priorities of the individual Furniture Manufacturer. Hence it is important to remember that the saw so purchased is required, over a period of time, to satisfy a range of often conflicting objectives for the same system. Thus the initial requirement, for the Furniture Manufacturer, at the purchasing stage is to:

(a) Identify the relevant factors;

As the numerous factors are determined their relationships can be identified and incorporated into a generalised model of the Furniture

Manufacturers system. This stage will require the participation from both the technical and practical members within the organisation.

(b) Evaluate the outcome that can be expected from each sawing machine option:

The essential requirement to ensure that this stage of the evaluation is carried out correctly is a representative set of panel / board size /quantities. It is only by simulating the sawing operational requirement, which requires a representative panel/board data set, that the design characteristic of the saw can be correctly evaluated.

(c) Select the sawing machine that offers the best range of possible options;

This demands that at the initial stage an open budget should initially be set, rather than fixing a budget then fitting the saw to that budget. In addition, the capital cost of the various sawing machines should be evaluated against their respective WASTAGE COSTS.

Some saws require additional trim cuts, whilst other sawing machines require that the last strip width must be greater than 200mm. In such circumstances although the same cutting pattern is required to be cut, the resultant wastage costs will vary, perhaps significantly?

(d) Define a set of cutting patterns and the volume throughput required.

It is essential that the Furniture Manufacturer provides the Sawing Machine Manufacturer with a set of cutting patterns that includes a cross section of cutting pattern complexities. And this cutting pattern set should never be altered or amended during the evaluation of the specific sawing machine. Too simple a level of cutting pattern complexity will enable the saw to easily produce a high volume output figure and hence without a defined set of cutting patterns the Saw Machinery Manufacturer is liable to assume the simplest cutting patterns so that the volume throughput, required by the Furniture Manufacturer, is achieved.

9.7.1 Identification of the Relevant Factors for the Simulation Model:

The identification of the relevant factors for inclusion into our simulation model followed two approaches, namely:

(a) Detailed discussions with the interested parties of Saw Manufacturers and their Agents; and Furniture Manufacturers.

(b) By using the cognitive maps of the Furniture Industry model.

Method

Detailed beliefs as to what was considered important were elicited from the interested parties. This enabled numerous hypotheses to be thought through using the Furniture Industry Model, developed by the cognitive mapping approach as described in Chapter Three. The resultant output from the Furniture Industry Model - basically the maps of the inter-relationships of the variables, Saw design; Waste Levels; Pattern Complexity; and Volume, were then discussed with a cross section of Furniture Manufacturers to validate the assumptions and implications that were suggested by the various cognitive maps.

9.7.2 Factors to be Considered at the Saw Purchasing Decision:

This communication/validation loop was repeated many times until the following robust listing of the relevant factors emerged:

* Volume Requirement
* Requirement to consider panel size relationship and panel variety.
* Material to be cut
* Accuracy required by Furniture Manufacturer

* Saw Design
* Stack height of boards to be cut
* Additional attachments available
* Pattern complexity level
* Wastage levels
* Saw times
* Handling into and out of the saw
* Labour requirement
* Scheduling rules followed
* Service and technical back-up

Although these factors are given a ranking in Figure 28.0 the preference ranking is general rather than specific. The main reason being that individual Furniture Manufacturers will inevitably see one variable as being more important than another.

The significance of the variables are ranked as either high or low. The fact that service and technical back-up, from machinery suppliers has a low ranking is not meant to convey that this variable is given a low order of importance by the Furniture Manufacturers. In practice the level of service and technical back-up is at such a high level that Furniture Manufacturers are less concerned with this variable than with the others.

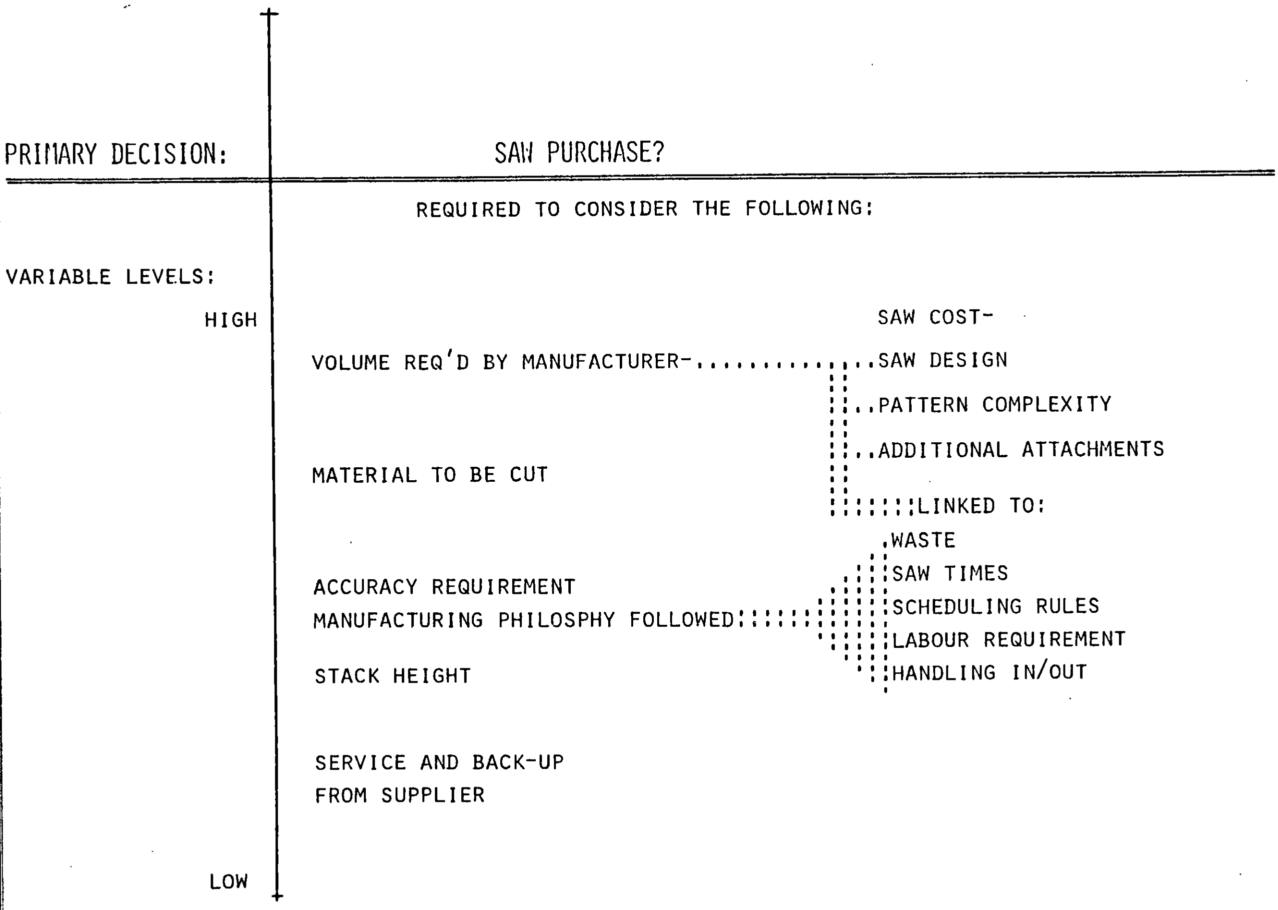


FIGURE 28.0 SAW PURCHASING DECISION : PRIMARY FACTORS

9.8 THE GOVERNING VARIABLES EXPLAINED:

In using the current approach to saw selection, a major criticism was that the decision variables used were of a general nature and as such were not amenable to detailed analysis. For example, the pre-occupation, by the Furniture Manufacturers to the volume variable is correct, although for the wrong reason. What is overlooked is that volume is a secondary variable in as much as it is controlled and governed by the following interacting and often conflicting primary variables:

* Saw design
* Panel variety
* Pattern complexity
* Scheduling rules

Given that the manipulation of these variables can result in a wide range of possible and plausible answers to the question:

"What volume requirement do you wish from the Sawing Machine?"

then particular attention has to be paid by Furniture Manufacturers to the way in which they, rather than the Machinery Suppliers, structure the Saw Purchasing Decision. So there can be no misunderstanding as to the effect that these variables have on the volume throughput per hour, we added the following information:

9.8.1 Panel Variety:

The relationship of panel variety and order quantities to board size and saw design plays a significant part in identifying the correct saw and the attachments that may be required for a specific volume throughput. Failure to examine this area in detail invariably results in the problem of low volume experienced by some Furniture Manufacturers. It is not sufficient to use general unit output values such as M3 per week or month. Rather actual panel order quantities and board details are required, which are representative of the current and future production mix which the proposed sawing machine will be required to cut.

9.8.2 Scheduling Rules:

At the managerial level the scheduling rules are about satisfying customers by meeting delivery promises (sales) and of maximising machine utilisation (production), whilst keeping material costs (waste levels) below some costed figure. At the operational level however, in primary conversion these conflicitng objectives are formulated, albeit sub-consciously into rules, as previously mentioned in Chapter Five. For example decisions on:

- can extra's be allowed?
- are the panels sequenced before the saw and re-sequenced for the remaining machining operations after the saw or are the panels only sequenced at the saw?
- what are the maximum panel discontinuities that are permitted?
- always cut to maximise the stack height of the saw? This would of course result in increased volume through the saw, however, extra panels would be produced.
- maximum number of different panel types permitted on one cutting pattern. If there are too many panel types, the unloading operation cycle tends to take longer than the actual cutting operation and hence volume throughput goes down.

The scheduling rules that the Planner works on then, although being managerially defined are often refined at the operational level to accommodate the practicalities of the volume variable. If the sawing machine is initially under specified then the Planners job of obtaining volume throughput can only be achieved by trading-off the variables of pattern complexity and waste levels; overtime being discounted.

9.8.3 Saw Design:

Different saws have different design characteristics and hence it is essential that a full and detailed understanding of these characteristics, and how, if at all, they effect the variables of wastage levels; volume and pattern complexity is obtained.

9.8.4 Pattern Complexity:

In general the greater the complexity of the cutting pattern the lower the volume cut in a fixed unit of time. ie. sawing cost per unit increase. As a direct result of this increase of pattern complexity there is also the probability that the waste levels will be lower. Hence the Planners requirement from the saw is often to have significant over capacity in the volume area so that it is possible to trade reduced volume for gains in material savings.

9.9 THE SIMULATION MODEL APPROACH TO THE SAW PURCHASING DECISION

It is perhaps useful as a starting point to re-iterate the problem and to define what we expect from the simulation approach to the Saw Purchasing decision.

The problem can best be described in two parts:

PART 1.0 There are a number of possible cutting machines available to the Furniture Manufacturer. Each sawing machine will have definable characteristics which are required to be understood. The cost of the machine need not necessarily reflect the level of cutting sophistication.

PART 2.0 The Furniture Manufacturer is required to sub-divide, by use of a sawing machine, large rectangular sheets of chipboard into the smaller panel order sizes which go to make up the furniture product. Although individual Furniture Manufacturers will have their own specific requirements re which saw to purchase the following factors are generally used by all, when considering the actual purchasing decision:

* Volume throughput per unit of time;
* Resultant waste costs associated with the proposed saw;
* Labour costs associated with the proposed saw;

* Overall cost of the sawing machine.

The objective of the simulation approach to the Saw Purchasing Decision is to identify the sawing machine that results in the minimum cost of the primary conversion operation. By adopting such an approach the Furniture Manufacturer is required to structure and evaluate in a more rational way all the possible options that are available. Currently the manual approach to this decision problem is under estimated by the Furniture Manufacturer, with the result that many 2dcp become difficult, if not impossible to solve without replacement of the current sawing machinery.

9.9.1 Simulation Procedure:

The proposed simulation procedure is now detailed. For clarity, additional notes are given on the righthand side of the block flow chart.

	ADDITIONAL NOTES:
START	
SELECT PANEL/BOARD DATA SET	The user is required to generate a set of panel/ board inputs that reflect a typical sales order mix. Where a typical order set is not available, then a number of data sets should be used.
DETERMINE MACHINE CHARACTERISTICS	From reading of the sales literature and from other

	sources, define the operating characteristics of all the saws.
IDENTIFY VOLUME REQ'MET set upper and lower bounds	Because the volume variable is the link pin to so many other variables it is important to define the upper and lower volume req't.
PATTERN GENERATION	Set parameters to reflex the current saw under analysis Initially restrict the level of pattern complexity to being simple.
INPUT PANEL & BOARD DETAILS	The panels are grouped by colour and in some cases are pre-sequenced for machine preference and or priority or orders.
COMPLETE SIMULATION	For the panel/board data input complete simulation runs for each level of cutting pattern complexity. * NOTE: some saws will be unable to cut above a certain level and hence their shortcoming can easily be identified.

COMPUTE RESULTS FROM EACH SIMULATION RUN AND PLOT GRAPHS

END

9.10 TYPICAL RESULTS FROM SAW ANALYSIS MODEL

The following figures illustrate typical results from the saw analysis model - SAM.

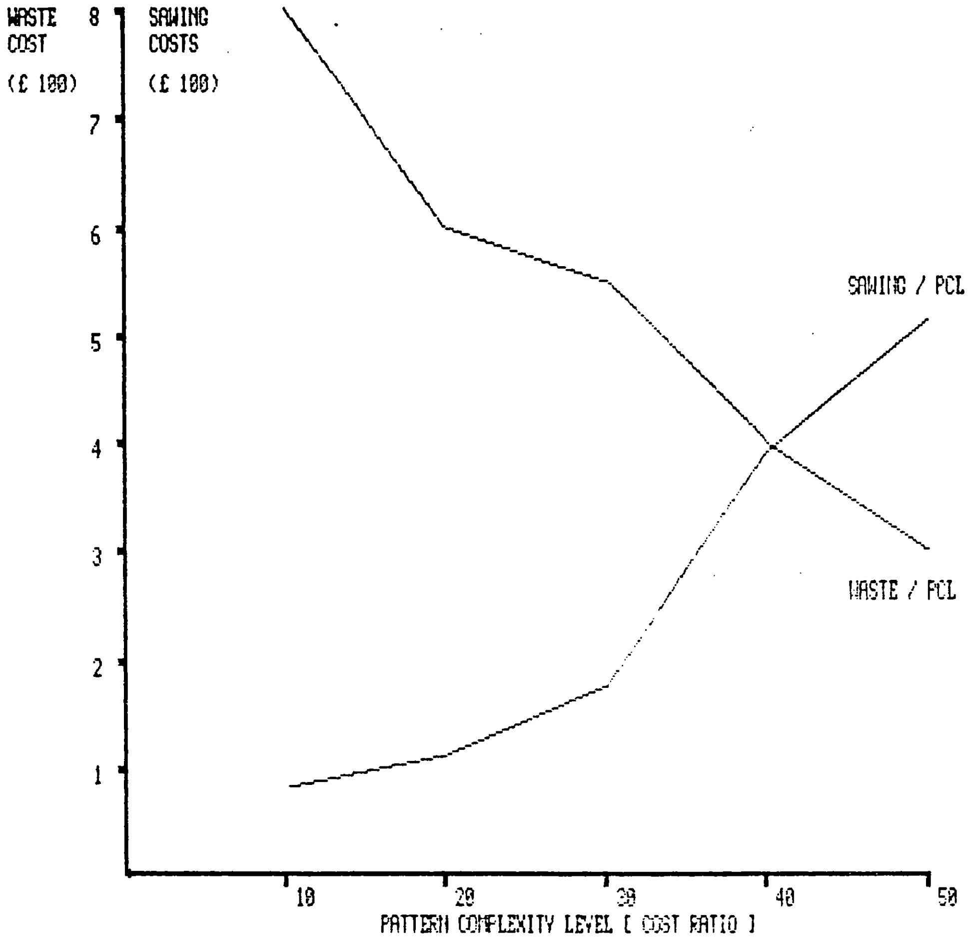


FIGURE 29.0 PRIMARY CONVERSION : TOTAL COSTS.

Notes for Figure 29.0

1. The term 'cost factor' is defined as the relationship between the cost of waste and the cost incurred in cutting.
2. The mathematical representation of the term 'cost factor' can be calculated from:

$$\frac{\text{Volume x Material cost}}{\text{Sawing Costs}}$$

Comments on Figure 29.0

1. Not surprisingly with low pattern complexity, the cost of waste is exceedingly high. As the level of pattern complexity is increased, the waste cost decreases. The opposite is the case for the sawing costs - The large increase between 30-40 is due to the fact that head-cutting and 15% off-line cutting was permitted.
2. For clarity, only one sawing machine is represented in Figure 29.0.Clearly the same simulation run, with modified parameters for pattern complexity level and saving time, can be undertaken for additional sawing machines, and their results also graphed. The graphical results identify the following information to the Furniture Manufacturer:

   * cost of waste material for each saw
   * sawing hours required for each level of pattern complexity

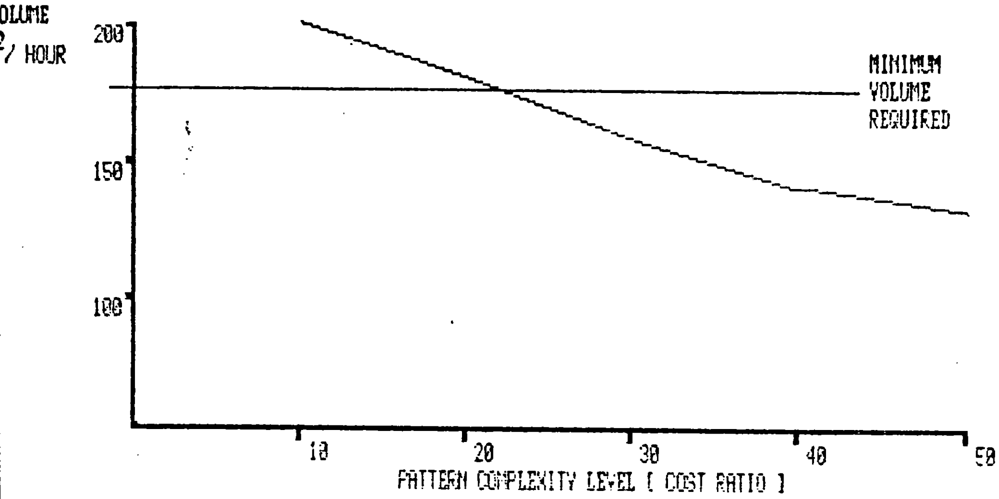


FIGURE 30.0 IDENTIFICATION OF VOLUME REQUIREMENT.

Comments on Figure 30.0

1. The graph in figure 30 represents the volume throughput possible for different levels of pattern complexity (cost ratio). The volume output figures have been calculated from the saw time/pattern complexity level results in figure 29.0.

2. The minimum volume requirement line in figure 30 indicates the minimum volume per hour required by this company. The serious reductions in achieving this volume throughput leads to higher unit costs.

3. As can be clearly seen from figure 30 the highest pattern complexity level possible, given the constraint on volume throughput is approximately 20. The implications of the cost of waste, as seen from figure 29, is alarming as this Furniture Manufacturer discovered.

4. The major problems in this specific case were related to:

   a) The Furniture Manufacturer had not designed the panel sizes to fit specific board sizes. The result being high waste levels, unless cutting pattern complexity was increased significantly.

   b) The majority of the panel sizes were very small and hence the time required for cross-cutting - the controlling factor for the proposed saw configuration - was very high.

   c) The saw manufacturers had not appreciated the high amount of cross-cutting required and hence had configured the saw with a large cross-cut throat width : nor had they understood the necessity for complex multi-staggered cutting patterns.

5. The solution to this saw purchase problem was as follows:

   a) Minimise the cross-cut saw throat width.

   b) Introduce a length alignment device thereby reducing the amount of time required in the cross-cut cycle time.

   c) Introduce a parameter in the computer pattern generator which took into account the necessity to minimise the number of cross-cuts in the strips.

   d) This resulted in the level of pattern complexity being moved from 20 to 30, still maintaining the volume throughput at 150 sq.m/hr.

9.11 SUMMARY

The Saw Analysis model described above has been used on numerous occasions to assist individual Furniture Manufacturers fully understand and hence make better, more informed saw purchasing decisions. In addition to preventing under specification of saws; purchasing of saws that fitted budgets which were no better than current sawing machines the simulation model has also provided a vehicle whereby the significant purchasing decision relating to the Furniture Manufacturers sawing machinery can be directly followed by the Purchaser and more importantly, fully understood.

It is self evident that wastage levels at the 2dc stage, in the manufacture of furniture are controlled by the initial design of the furniture model. Given however that furniture is synonymous with fashion and that squarish, modular boxes do not correlate to sales volume, designers tend to deviate from the simple solution of matching panel sizes to known board sizes with the result that the capabilities of the sawing machinery and the skill of the Planner are required to be combined to generate cutting patterns that satisfy a continuing changing set of circumstances. Hence the Saw Purchasing decision, for the Furniture Manufacturer is not the simple "replacement machine" problem it first appears. On the contrary, it is a complex, inter-related set of problem issues which tends to bound and control, in a mechanistic way the Furniture Manufacturers 2dc problem. Failure to treat it as such will inevitably lead to greater manufacturing costs at the primary conversion operation than need be. Certainly by paying attention to detail the sawing machinery so purchased can provide a greater financial payback than any other machine that the Furniture Manufacturer uses.

CHAPTER TEN: CONCLUSIONS

10.1 PREVIOUS SOLUTIONS FOR 2DC PROBLEMS HAVE BEEN UNDER DEFINED AND HENCE INCORRECTLY FORMULATED

As we have shown in the Chapters Three and Four, the nature of the production processes, combined with the technology components makes the previously proposed heuristic and linear programming solution models inappropriate. The main reasons for this are;

(a) Previous heuristic 2DC problem solutions have been orientated towards the Glass and Paper industries rather than towards the Furniture industry. Given that the technology and manufacturing processes of the industries are dissimilar, the previously used heuristic procedures do not function within the furniture industry.

(b) The linear programming models, although offering solutions which minimise waste, perform poorly with regard to the non-linear components of the practical 2DC problem, namely: Pattern changes; Order spread and Ratio of cutting patterns to orders.

This lack of universal approval and usage of the previous 2DC trim solution models is not due to mathematical inability of the proposed solutions but rather relates to the fact that the cutting problem, in general terms has been under defined and hence incorrectly formulated.

10.2 ESSENTIAL THAT THE PROBLEM IS UNDERSTOOD

The first step in the problem solving framework consists of three inter-connected steps rolled into one, namely:

(1) Detect that a problem exists;

(2) Identify the problematical aspects of the problem - the technology components and the actors within the problem domain;

(3) Define the problem accurately.

Whilst in theory we might all ascribe to adopting such a procedure, in practice, the second part of this first step is often only completed in a cursory manner. In previously documented 2DC problems, for example, no information exists which indicates that the manual methods adopted by Planners in generating cutting patterns have been studied, documented and fully understood. Yet it is axiomatic that the chances of finding a satisfactory solution to a problem are highest when the person trying to solve it understands it thoroughly.

The ability to gain an understanding about a problem however, depends initially upon the discovery and identification of the essential features and how they are related, if at all. Secondly, these essential features are required to be embedded in one's mind in such a manner which permits a pattern: MODEL <====> SOLUTION to be perceived, irrespective of the changing inter-relation ships between the variables contained within the problem. To date, for example, the 2DC problem model builders have identified the essential problem feature as being the minimisation of waste. Although this single decision criterion may appear to be theoretically correct other industrial issues, such as:

- volume throughput per hour .... Vt
- number of patterns to orders .... Pa:Or
- spread of orders across c'patterns .... Sp:Or
- handling and sorting issues .... Ha:Si

modify the solution direction that is required in practice from the waste minimisation goal to be more orientated towards maximising the volume throughput, whilst minimising the number of cutting patterns to order ratio; the spread of the order across too many cutting patterns, subject to maintaining the waste level to some threshold limit, ie. the goal orientation of:

Vt max

min Pa:Or ; Sp Or ; Ha Si

subject to: waste <= threshold limit Wth

where Vt;Pa:Or;sP Or;Ha Si and Wth, are User defined values which can be changed within the pattern generation process by the Planner. In reality, model builders who advocate solutions based on linear or heuristic procedures which are predominantly waste orientated do not really understand the total, complex inter-related nature of the (Furniture Manufacturers) trim problem.

10.3 TIME MUST BE SPENT ON IDENTIFYING THE PROBLEMATICAL CHARACTERISTICS OF THE PROBLEM

In the course of identifying and formulating the problematical characteristics of the Furniture Manufacturers 2DC problem; the second part of the suggested problem framework : it became obvious that the solution is in part controlled by managerial decisions which are external to the Planners decision space, eg.

(a) The Saw Purchase Decision: The sawing machine so purchased defines the max-min level of pattern complexity that can be achieved at the sawing operation and hence indirectly controls the volume throughput and the level of waste that is attainable for the individual Furniture Manufacturer.

(b) Board Panel Size Relationships: In many cases the design department design with little if any thought being given to the batching requirements that occur later in the Planning office. As some Furniture Manufacturers are slowly begining to realise, the implications of paying insufficient attention to the inter-relationships of:

- panel: board size; // volume : waste and cost of sawing cannot be easily rectified at the batch planning stage by the Planner.

At the batch planning stage - the cutting pattern generation phase - the Planners main function is not directly related to waste minimisation but to minimising the inbalance for the whole system. For example, there is little to be gained in generating cutting patterns which have minimum waste if the resultant pattern complexity level is too high so that insufficient volume is produced at the sawing operation. In practise we have discovered that the main pre-occupation of Planners is to generate cutting patterns which although not optimal from a single decision criterion, are balanced when viewed against the multi-decision criteria of:

1. WASTE
2. VOLUME
3. PATTERN to ORDER RATIO
4. SEQUENCING
5. HANDLING and SORTING ISSUES

Given that these first two decision criteria are generally imposed, as we have mentioned above, the Planner is more directly concerned with the more practical.knowledge based third.forth and fifth decision goals of. (i) pattern to order ratio; sequencing and handling and sorting issues respectively. rather than the goals of waste and volume. These problematical decision characteristics were delegated to serve as problem constraints rather than pointers which could better outline the decision space and aid the search procedure of cutting patterns which balance the Planners multi-decision criteria trim problem. As the tabulated results on page 199 indicate, it is possible to obtain cutting patterns which are close to the waste optimal criterion but which also satisfy the other more non-linear, practical decision criteria. The requirement, however, is that time must be spent on identifying all of the problematical characteristics of the real world problem: the technology components as well as the more easily identifiable, well ordered mathematical facts.

10.4 THE WAY IN WHICH THE PROBLEM IS DEFINED INFLUENCES OUR ACTIONS TO SOLVE IT

The third part of the suggested problem formulation framework is probably the most important step of all: Defining the correct problem. As can be seen from our recent papers; (see appendix 5), there are many actors involved in the Furniture Manufacturers 2DC problem. Whilst all of these different actors would agree that the central issues revolve around the waste issue, all would place a slightly different emphasis on the importance of the wastage variable. Of all the actors involved, however, the Planner is charged with defining the solution from a practical point of view.

The phrase "practical point of view" is important as it highlights the fact that the current LP solution strategies are defined more by mathematical linear relationships than by practical equations which reflect the often untidy, ambiguous real world trim problem. As our research illustrates, the knowledge required and the concepts used in the practical definition of the trim problem, by the Planner, are more complex and less sharply defined than the mathematical definition used in the LP approach.

Whilst the modelling of practical problems requires more understanding than problems which are more mathematically definable, the major differences lie in the nature of the knowledge required and how that knowledge is subsequently used to model the problem:

The Planner, on the one hand, relies on his experience and knowledge base which has been built up over a number of years. Hence when confronted with a panel order list the Planner is able to : (i) give meaning to that list that is beyond simple lexicographical ordering. (ii) change the importance and structure of the decision criteria. (iii) amend the data; the concept of tight cutting or Z cutting specific panels, even though no Z cutting is permitted. (iv) the increasing/decreasing of panel quantities. (v) the inclusion of panels not previously contained in the order list.

In contrast the mathematical approach to problem structure and definition demands that we start from a set of clear, well ordered concepts: All data and contradictions are required to be stated explicitly and once taken into account cannot be easily changed or modified. The result being that in modelling the problem from a mathematical base we are often forced to settle for an approximation of the problem. This approximation excluding the seemingly unrelated jumble of facts that go to make up the practical information knowledge base that differentiates the superior manual heuristic approach used by Planners.

To date the majority of Operational Researchers have defined and understood only part of the Planners trim problem: The waste minimisation part. Whilst the minimisation of waste is obviously a significant goal, excluding the more practical, often untidy non-linear relation ships results in a solution procedure which although satisfying the Operational Researcher, is less than useful from the Planners point of view.

10.5 A MORE APPROPRIATE SOLUTION TO THE FURNITURE MANUFACTURERS 2DC PROBLEM IS A MODEL WHICH IS BASED ON MULTI DECISION CRITERIA

As we have illustrated in figure 9.0, page 73, the Furniture Manufacturers 2DC problem encompasses a large cross section of inter-related problem issues. Although the wastage goal is a significant problem characteristic, it is but one of the many issues that the Planner is required to consider when generating cutting patterns. In practise the 2DC problem resides in an ill defined and very loosely structured decision space. The result being that an optimal solution based on any one single decision criterion will invariably fail to model the real world problem faced by the Planner. The approach that we have found to work in practise is based on the following multi decision criteria grid:

No.	Decision criteria:	s.t.Threshold Values
DC1	Max Volume throughput	DC 1, 3 and 4
DC2	Max number of panel orders closed per cutting pattern;	DC 1, 2 and 4
DC3	Min total waste from the complete set of cutting patterns	DC 2, 3 and 4
DC4	Min number of times a panel order appears in the cutting patterns	DC 1, 2 and 3

Where the Planner supplies the values for the threshold parameters and hence is in the position to control the directionality of the solution procedure for the first time.

Irrespective of how the threshold values are set our proposed heuristic problem reduction solution procedure does not guarantee optimality for any one of the defined decision criteria, DC 1 through 4. The generated cutting patterns, however, are often very close to the optimal waste levels that are possible to achieve, as indicated by the table on page 199. The overall result being that these generated cutting patterns are more acceptable when viewed against the other, more industrial problem characteristics of volume; number of cutting patterns and order sequencing - the rocks where the previous approaches have so often floundered. We can therefore justly claim, that our proposed approach is far more appropriate and robust than the waste dominant LP approach and more importantly reflects the actual decision process of the Planner.

10.6 A TEAM: THE PLANNER + COMPUTER.

The main objective of this research has been to improve managerial effectiveness in the area of the Furniture Manufacturers 2DC problem. The majority of the previous work in this area concentrated on the more easily definable mathematical elements of the problem rather than on understanding and linking in the technology related elements contained within the problem. As we have discovered within the context of the 2DC problem, Planners, (Decision Makers) tend to analyse their 2DC problem on the basis of differences and or changes in the manufacturing environment: ie. value judgements rather than scientific, numerical facts. When confronted with the panel order requirement list, Planners identify the relevant goal structure which is most pertinent to the situation. The result being that within one pattern generation procedure many different goal structures may be required. It is little wonder then that to date few LP orientated 2DC models have been sufficiently robust enough to provide the support that is so obviously needed in the 2DC decision process. In the heuristic 2DC solution that this research proposes the model framework has been structured so that the strengths of the Planner are complemented by the speed of the computer: they work as a team.

The Planner is able, via the User Defined routine and the panel order input structure, to assist the computer in ordering the panel list. (ie. currently the lexicographical ordering procedure does not have the ability to recognise patterns of data, eg. panels which have the same order requirements.

and process these panels first. This pre-panel selection procedure, by the Planner, is the result of many years of practical experience and to date is not fully understood and hence not incorporated into our proposed solution procedure.)

Whilst the computer system offers the Planner the facility to:

- examine all the possible goals contained within his decision space;
- easily perform "what if" analysis;
- perform sensitivity tests on panel and board sizes;
- provide the means of achieving consistency of results;

Currently the time pressure that the Planner works under prevents him from examining all but a few of the 2DC pattern alternatives.

10.7 BY UNDERSTANDING THE COMPLEX NATURE OF THEIR 2DC PROBLEM, FURNITURE MANUFACTURER'S CAN GAIN SIGNIFICANT ECONOMICAL ADVANTAGE

As pointed out in Chapters Three and Four, there are two main areas that the Furniture Manufacturer should pay more attention to, namely:

(a) The design of panel sizes to master board sizes and the implication of the number of panel sizes that are required across the model range; ie. the panel profile;

(b) The saw Purchase Decision;

(a) A HIGH PERCENTAGE OF THE FURNITURE MANUFACTURER'S 2DC PROBLEM IS SELF INFLICTED:

In many cases the development of new models is more fashion, marketing orientated; (price point relationship) rather than technology material cost related. The end result being that little attention is given to the panel board size profile until too late in the decision making process. Hence it is not unusual to find that the manufacturing side of the business is required to produce panel sizes which are within five to ten mm of one another. This state of affairs results in Z cutting; lower order cutting pattern run lengths; increase in the number of different panel types that are required to be held/manufactured by the manufacturing unit. As our work with one Furniture Manufacturer has indicated, it is possible to significantly reduce the number of panels types - length and width sizes - without losing flexibility and hence reduce both the cost of waste and the level of panel stocks. As many Furniture Manufacturer's are slowly appreciating, the best opportunity for managerial control of material utilisation is at the start of the manufacturing system: the design stage, even with the assistance of the computer bad panel/board relationships cannot be rectified.

(b) THE SAW PURCHASE DECISION : A CRITICAL DECISION

As can be seen from Chapter Nine, the correct decision vis-a-vis the sawing machine that will be used in the primary conversion area has significant implications on the 2DC problem. In the majority of cases the Saw Purchase Decision is treated too simply by the Furniture Manufacturer. Little if any actual cutting patterns are supplied to the machine supplier so that volume capacities, saw times and other operational details like the necessity for additional trim cuts etc. can be thoroughly checked out. In practise the sawing machine should permit the maximum cutting pattern level of complexity to be cut. This enables the Planner to trade off waste : volume / sawing hours required. Too low a level of pattern complexity from the sawing machine, although giving good volume and low sawing hours, often results in higher wasts costs.

10.8 FURTHER RESEARCH

ADDITIONAL RESEARCH IS CLEARLY REQUIRED IN THE AREAS OF:

* HOW THE PLANNER MENTALLY CONSTRUCTS HIS 2DC PROBLEM: HOW THE TRADE-OFFS ARE HANDLED:
* HOW THE INITIAL ANALYSIS OF THE PANEL ORDER LIST IS CARRIED OUT:

As briefly outlined in Chapter Six, the characteristics that go to structure the individual Planners 2DC problem are not static but are dynamic and are largely dependent upon the Planners perception of the current decision space. In some circumstances the decision goal will be volume, in others, waste. Clearly the initial identification of four operational goals that assists the Planner in structuring his 2DC problem requires further research : the requirement is to understand how Planners think what to think about.

An additional area of research that we are currently undertaking with two Planners is related to how they initially order the panel order list. As we have pointed out, the major problem with the problem reduction method of generating cutting patterns is that large panels are required to be taken as early as possible in the pattern generation process. In studying Planners in action however, this simple rule is not necessarily followed. It appears from the research to date that the significant information required to order the list cannot be found from a normative ranking approach but resides and is in part, a function of the Planners knowledge and experience base.

******* APPENDICES *******

A1: EQUATIONS FOR CALCULATING SAW TIME ON ANGULAR SYSTEMS.

A2: EQUATIONS FOR CALCULATING SAW TIME FOR TEUTOMATIC SAW.

A3: CUTTING PATTERN OUTPUT DETAILS RE COMPARISION TEST IN CHAPTER EIGHT.

A4: DETAILED OUTPUT FROM POPS ALGORITHM: USES TEST NO. 7.

******* PUBLISHED PAPERS *******

[1]. The Third Dimension of Two Dimensional Cutting:

OMEGA. The Int.Jl of Mgmt Sci.Vol 10.No.1 pp 81 to 87 1982.

[2]. A Multi-Objective Decision Problem: The Furniture Manufacturer's 2-Dimensional Cutting or Trim Problem:

Short Paper presented at the I.M.A. International Conference, Manchester,England 1982.

[3]. Cutting Through Problems:

Prospect Award Paper of the U.K. Operational Research Society, 1982.To be presented at the 1983 OR conference.

APPENDIX A1:

This appendix presents in detail the saw time equations of the sawing approach commonly referred to as the " Angular System Approach" . These equations are necessary so that the saw time and hence the volume throughput for the differing levels of pattern complexity can be calculated.

The vast majority of the medium to large Furniture Manufacturers use the Angular sawing system approach to primary conversion.

APPENDICES:

A1. EQUATIONS FOR GIBEN ANGULAR SYSTEM.

Introduction.

The objective of appendix A1 is to present,in detail,the equations required so that the time and the volume throughput,for the angular system; the sawing system most used by Furniture Manufacturers in the U.K. can be calculated.

It should be noted that all the equations relate to a notional saw model and hence although the mathematical theory is correct the values for some of the variables will obviously differ from Furniture Manufacturer to Furniture Manufacturer.

CALCULATION OF SAW EQUATIONS.

Although there are numerous angular systems available we restricted our investigations to the Giben model 17 and Giben model 19.

The first requirement is to identify the total elements that go to make up the machine cycle.This was achieved from detail study of the two machine types at Crosby Furniture,Sheffield and Homeworthy Furniture, Sunderland,and is detailed on pages 81 to 88 inclusive.Given these machine elements the second requirement is to identify and structure the natural breakpoints so that the necessary equations can be formulated.ie.

ELEMENT	DESCRIPTION	USED ON MODELS	
K 1	Length cutting time + slow down of length pusher	17	19
K 2	Total feeding time of L-pusher	17	19
K 3	Time for transfer unit to clear l-cutting line	17	19
K 10	Cross cutting time + slow down of cross pusher	17	19
K 20	Total feeding time of cross pusher	*	19
K 21	Total feeding time of cross pusher	17	*
K 30	Delay time for unloading	17	19
K 40	Return time of cross pusher	*	19
K 41	Return time of cross pusher	17	*

AN APPROXIMATION:

An approximation of the above machine element breakpoints is possible, as shown by Harrison and Suomenin, ( ). This approximation permitting the following simplified saw equations to be derived.

Saw time = Total machine cycle time * Number of cycles

where the machine cycle time is calculated from:

Number of cuts * K 1 + K 2 + K 3

given that

K 1 = the time for the pusher to slow down and the time for one cutting cycle.

K 2 = the total pusher feeding time.

K 3 = the time for the transfer unit to clear the length cutting line.

** Note that there are in effect two different sets of K1 and K2's - one for the length machine and one for the cross cut machine.

The Number of cycles is calculated from :

number of cycles = Number of boards to be cut for this cutting pattern
----
Stack height cut in one pass

The sawing time required for any cutting pattern can be determined by using the above equations and the following stepped procedure;

(a). Calculate time required for length cutting cycle.

(b). Calculate cutting time required for cross cutting cycle.

(c). Calculate the waiting time at the cross cut machine on the first pass.

Then the sawing time is simply calculated from:

Highest value of Length or Cross cut cycle time + Highest value of waiting time at cross cutting line on the first pass or length cutting time.

Examples of this approach to saw time calculations are now detailed:

WORKED EXAMPLES OF SAW TIME CALCULATIONS

Firstly we compute a look up table for No. of passes / time required for length and cross cut cycle times. ie

Length and cross cut timings:

L CUT	C CUT
K 1 37 sec	K 1 17 sec
K 2 33 sec	K 2 52 sec
K 3 30 sec	*

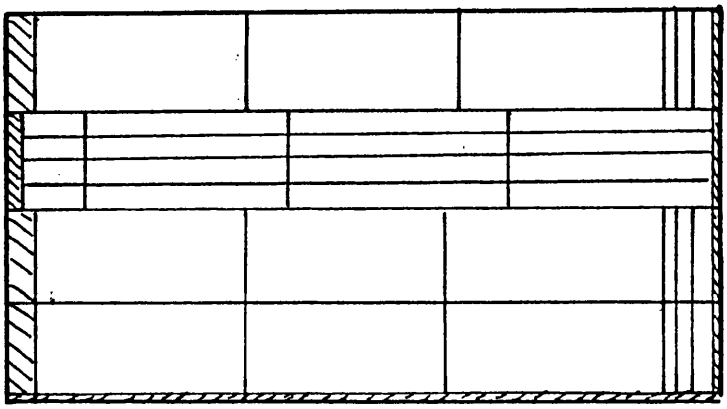
From these length and cross cut timing the following table can be derived which simplifies the calculation of length and cross cutting cycle times:

[(N * K1) + K2 + K3] ...... length cutting cycle.

(N * K1) + K2 ...... cross cutting cycle.

No. of passes	length time req'd	cross cutting time
1	100	69
2	137	86
3	174	103
4	211	120
5	248	137
6	285	154
7	322	171
8	359	188
9	396	205
10	433	222
11	*	239
12	*	256
13	*	273
14	*	290
15	*	307
16	*	324
17	*	341
18	*	358
19	*	375
20	*	392

Worked example A.



Length cutting time calculation:

No. of length cuts = 8 / time from look up table = 359 sec.

Cross cutting time calculation:

For strip 1.
No. of cross cuts = 7 / time from look up table = 183 sec

For strip 2.
No. of cross cuts = 5 / time from look up table = 147 sec

For strip 3.
No. of cross cuts = 7 / time from look up table = 183 sec

Total cross cutting time for strips 1 2 and 3 = 513 sec.

Given that the waiting time at the cross cut machine,on the first pass is lower than the length cutting cycle time then the total sawing time for this cutting pattern is:

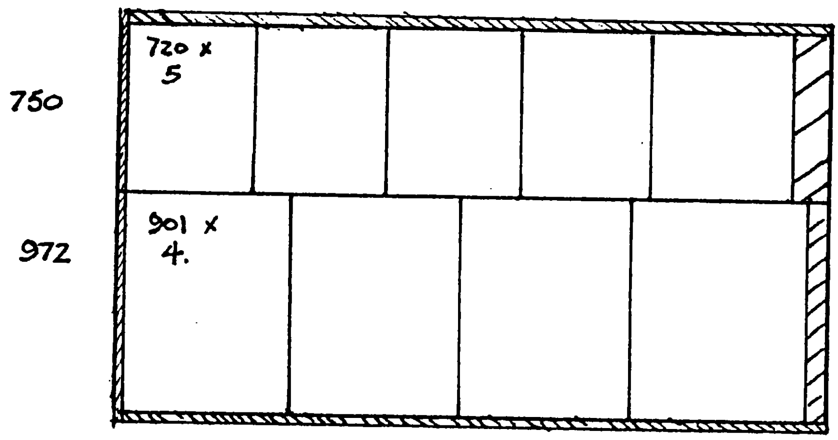
TOTAL SAWING TIME : (No. of Passes * 513) + 359 sec

given that 23 passes are required; ie. 5 boards are cut per pass, then

$$\frac{[(115/5) * 513] + 359}{60}$$

TOTAL SAWING TIME : 201 mins.

Worked Example B.



Length cutting time calculations:

No. of length cuts =4 / time fro look up table = 211 sec.

Cross cutting time calculations:

For strip 1.
No. of cross cuts = 5 / time from look up table = 137 sec.

For strip 2.
No. of cross cuts = 4 / time from look up table = 120 sec.

For strip 3.
No. of cross cuts = 10/ time from look up table = 222 sec.

Total cross cutting time for strips 1 2 and 3 = 479 sec.

Given that the wating time at the cross cut machine,on the first oass,is lower than the length cutting cycle time then the total sawing time for this cutting pattern is:

TOTAL SAWING TIME : (No. of Passes * 479) + 211 sec

given that 18 passes are required; ie. 5 boards are cut per pass,then,

$$\frac{[(90/5) * 479] + 211}{60}$$

TOTAL SAWING TIME : 147 mins.

APPENDIX A2.

This appendix details the machine elements of the N.C. controlled Teutomatic saw and presents the sawing equations so that the sawing time for the different levels of pattern complexity can be calculated.

Only four to five such saws are used by Furniture Manufacturers in the U.K. The main reasons for the lack of usage revolves around (1). The (assummed complexity) N.C. operation rather than the inadequacy of the saw. and (2). The inability of the saw to dimension a panel to the finished size without recourse to the tennoning line.

A2. SAW TIME EQUATIONS AND DETAILS OF PLOT CARD FOR TEUTOMATIC SAWING MACHINE.

Introduction.

This appendix details the machine element breakdown of the Teutomatic saw cutting cycle.The omission of these details from the main body of the thesis was for clarity reasons alone.

Due to the fact that the Teutomatic saw has been designed for control by punch card input - it also has a manual optional input - the identification of the total machine elements is relatively easily identified.The calculation of any machine cycle can be obtained from summing those machine elements required for a particular cutting pattern multiplied by their respective occurences.In addition,due to the fact that there is only one sawing line and that the waiting table may be required for staggered or head cutting patterns the loading,unloading onto the table must be included in the element breakdown.

The machine element breakdown for the Teutomatic saw are as follows:

ELEMENT	DESCRIPTION
LO.1	Transfer sheets from waiting position on roller bed to cutting table and square up.
LC.2	Saw index: For correct orientation and board length. (4 / 5 meters in length).
LC.3	Saw index: For correct orientation and board length. (2.5 / 4 meters).
IX.4	Initial saw index: Required when residual board has been reloaded onto table,when staggered pattern has been cut.
SR.5	Saw head returns to datumn point diagonally
SR.6	Saw head returns to datumn from oppisite edge.
BF.7	After completion of length cutting; element LC.2. move or backfeed length strips in bulk onto waiting table so that staggered cutting can take place.
CC.8	Index saw and cross cut.
OO.9	Off load staggerd cut panels and relaod residual board onto table:by keeping the residual board in one piece element LO.1 is automatically activated.

[illegible] Off load cutting table completly.

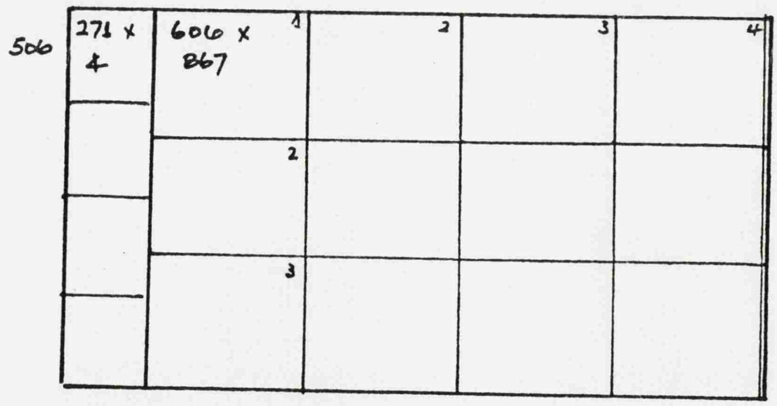
LS.11 Load stock sheets from waiting position on input conveyor to waiting station.

BH.12 After head cutting operation move or backfeed board to waiting position.

For each of the machine elements above it is possible to give a time value. To arrive at the total saw cycle time for a given cutting pattern the respective time values are allocated to the machine elements multiplied by their occurence and the manual elements; elements associated with loading;unloading,clearing aside waste strips etc. are required to be added. Therefore the sawing time required for any cutting pattern can be calculated from:

SAW TIME = TOTAL TIME FOR MACHINING ELEMENTS x OCCURENCES
+ MANUAL ELEMENTS x OCCURENCES.

For example given the following cutting pattern the time required on the Teutomatic saw would be :



1. Manual Element Calculations:

Off loading header part of board = 0.616 sm
Off loading main part of board = 2.106 sm

Total off loading time required = 2.722 sm

2. Machine Element Calculations:

Operation:	Element	Occu	time req'd	Abbreviated description
1.	LO.1	1	0.722	Sheets in and square up.
2.	CC.8	1	0.265	Saw index;cut across b'd
3.	SR.6	1	0.118	Saw returns to datumn
4.	BH.12	1	0.050	Backfeed b'd to w'table
5.	LC.3	4	0.720	Saw index 506 cut b'd.
* Head cut now completed.				
6.	SR.6	1	0.118	Saw h'd return to datumn
7.	LO.1	1	0.722	Sheets in from waiting table and square up.
8.	LC.3	3	0.570	Saw index 606 length cut
9.	SR.5	1	0.187	Saw return to datumn in diagonal movement.
10.	CC.8	4	1.06	Saw index 867 and cross cut board
11.	OC.10	1	0.630	Off load complete.

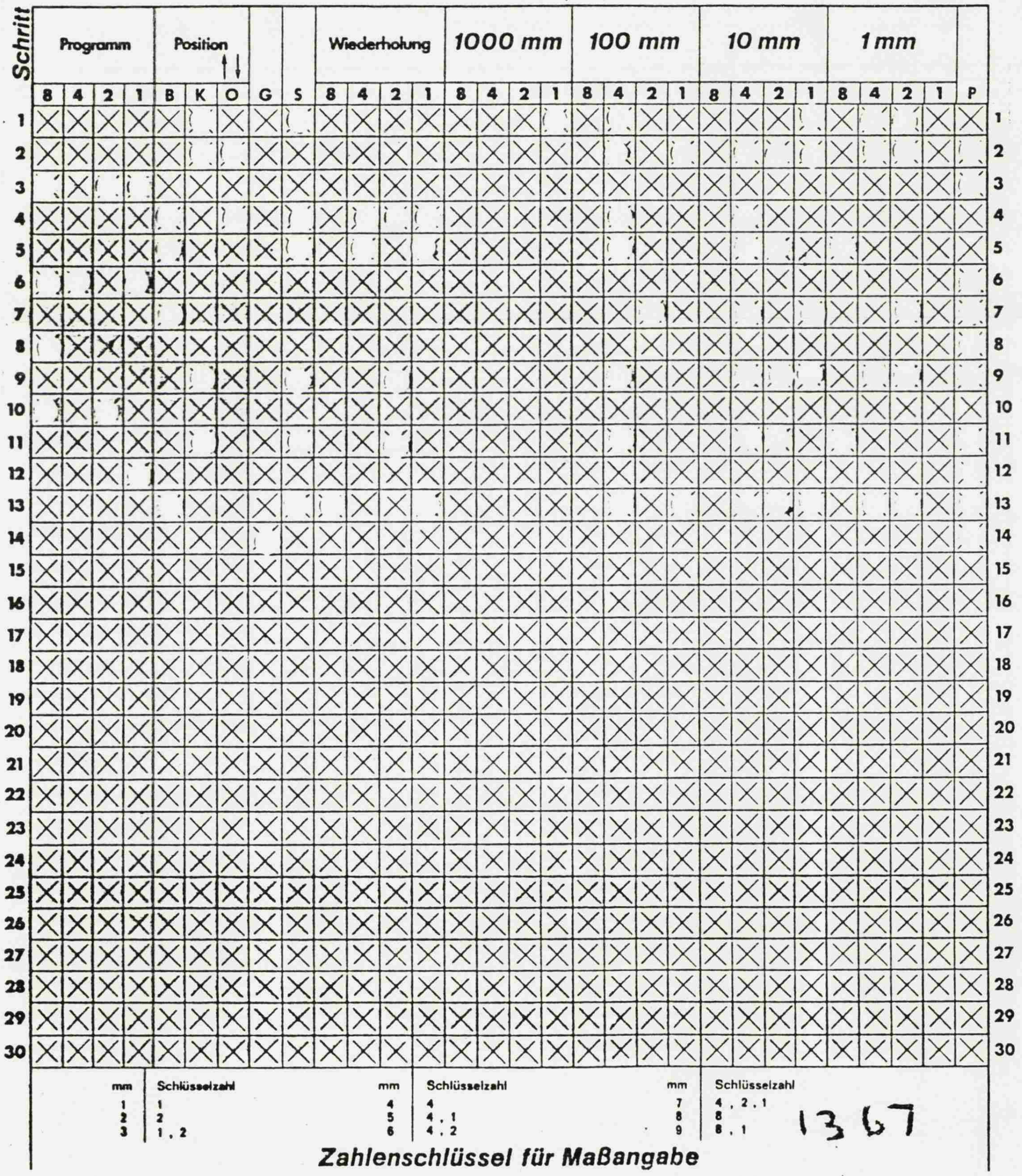
TOTAL MACHINING CYCLE 5.162 SM

THE PLOT CARD:

Once the cutting patterns have been decided upon the setting instructions for controlling the saw so that the pattern is cut correctly have to be transmitted onto a punched card; or Plot card as it is referred to. See following example:

Example of a Plot Card:

PLOT 727



The saw instructions,with respect to the cutting pattern,are punch in the approoiate PROGRAMM row/column.For example the 4 bit control pattern correspond to the previously detailed machine element breakdown: ie.

P R O G R A M M

8	4	2	1	Basic description of Command:
			*	Return cross cut to datum side.
		*		Return length cut to datum edge.
		*	*	Return len + cr cut back to datum
	*		*	Off load track 3: 2 and 1 stay clamped.
	*			Off load tracks 2 +3 :track 1 stays clamped
	*	*		Programm back to start.Panel stay clamped.
*				Return residual panels to table.Saw to datum
*		*		Off load H-Cut:Repos'panels:Saw to datum
*	*			Track 3 stays: tracks 1+2 to air lift.
*		*	*	Track 2 stays : track 1 to air lift.
*	*		*	Off load track 3: tracks 1 +2 to m/c bed.
*			*	Programme interupt.

These commands in effect control all the possible movements of the Clamps;Belts;Bridge ;Saw head and the movements of the boards onto and off the cutting table.In addition,because of the unique 270 degree rotation of the sawing head,it is also necessary to indicate whether the bridge is in the cutting station or the saw head itself: ie. the two options are:

B - Position for the cut with the bridge - ie. Bridge positions it self and remains locked and performs,with the saw head the cross cutting operation.

or

K - Position for the cut with the saw head and length cut with the bridge.

In addition the following positional commands are also available:

O - Used only in conjunction with the positional commands B and K when the saw head terminates at a position away from the datum.In such cases the next programme command to the machine must be the positional command O,thereby signalling that the next cut is required in datum direction.

G - Requests that the sawing programme terminates with automatic unloading of panels from machine bed to unloadfing table.

S - Indicating that the cutting requirement is to be repeated.Note that the first row position of S relates to the start command and as such cannot be used as a repeat instruction. The number of repeats is controlled by the columns under the heading " WIEDERHOLUNG ". All four holes punched in the row would indicate that the programme is to be repeated 15 times. ie.8+4+2+1

INPUT OF PANEL DIMENSIONS:

The input of panel dimensions are punched in the appropiate column and rows and follow the normal 4 bit logic.There is no necessity to compasate for the saw thichness as the programme automatically takes this into account.

PARITY BIT:

The final requirement is to chech for the parity bit. ie. Apart from the top line,which must contain an ODD number of punched holes all other lines must contain an EVEN number of punched holes.This is achieved by adding,where necessary, in the P column - far RH column - an extra hole.

APPENDIX A3.

This appendix provides the detailed cutting pattern output from the comparision test detailed in Chapter Eight.

For each of the six comparision tests the proposed heuristic solution and the Opticut LP computer model solution are detialed,respectively.

The parameters of both computer models were set so as to allow for extra panels to be cut,if so required.The upper limit set for extras was four percent of the total board area cut.

In the LP model the only goal considered (due to the model structure) was waste minimization.Whereas in the heuristic approach the models parmeters were set so as to identify the best set of cutting patterns for the specific goal selected by the Planner.At each generation stage the Planner was able to inter actively search around the total decision space before selection of the cutting pattern.In many cases the initial goal selected was high closure of orders per cutting pattern.If there were no such cutting patterns then a different goal(solution direction) was adopted.

Test No. 1.

number of panel orders 10

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PANEL REQUIREMENTS

NO.	PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
1.	PANEL 1.1.	1887	292	15	N	Y	570	10
2.	PANEL 1.2.	1887	292	15	N	Y	50	10
3.	PANEL 1.3.	1887	282	15	N	Y	50	10
4.	PANEL 1.4.	832	292	15	N	Y	420	10
5.	PANEL 1.5.	541	292	15	N	Y	150	10
6.	PANEL 1.6.	711	292	15	N	Y	440	10
7.	PANEL 1.7.	437	292	15	N	Y	260	10
8.	PANEL 1.8.	675	276	15	N	Y	365	10
9.	PANEL 1.9.	475	276	15	N	Y	635	10
10.	PANEL 1.10.	325	276	15	N	Y	880	10

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BOARD AVAILABILITY

NO.	BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
1.	BOARD 1.	5120	2070	15	30000

A

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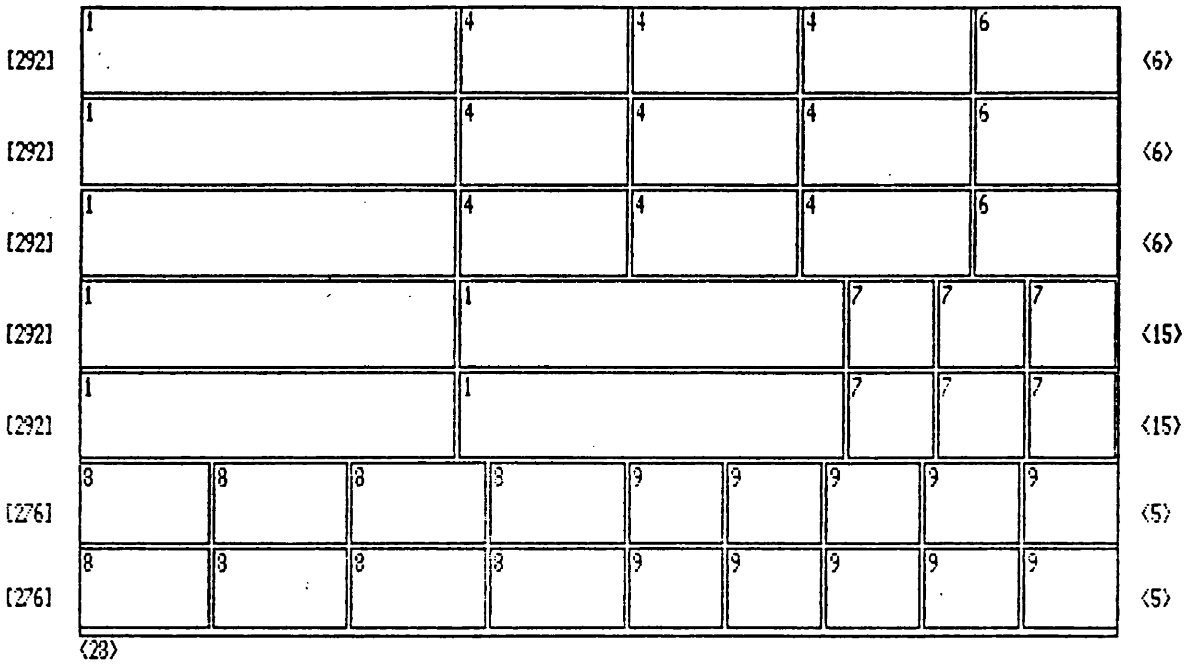
CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m^2)	% Panels	% Boards
Panel requirements :	848.63	100.07	92.04
Extras produced :	31.56	3.72	3.42
Board area used :	922.06	108.73	100.00
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	18.11	2.13	1.96
Edge trim :	0.00	0.00	0.00
Additional waste :	23.76	2.80	2.57
WASTAGE :	41.87	4.93	4.54

B

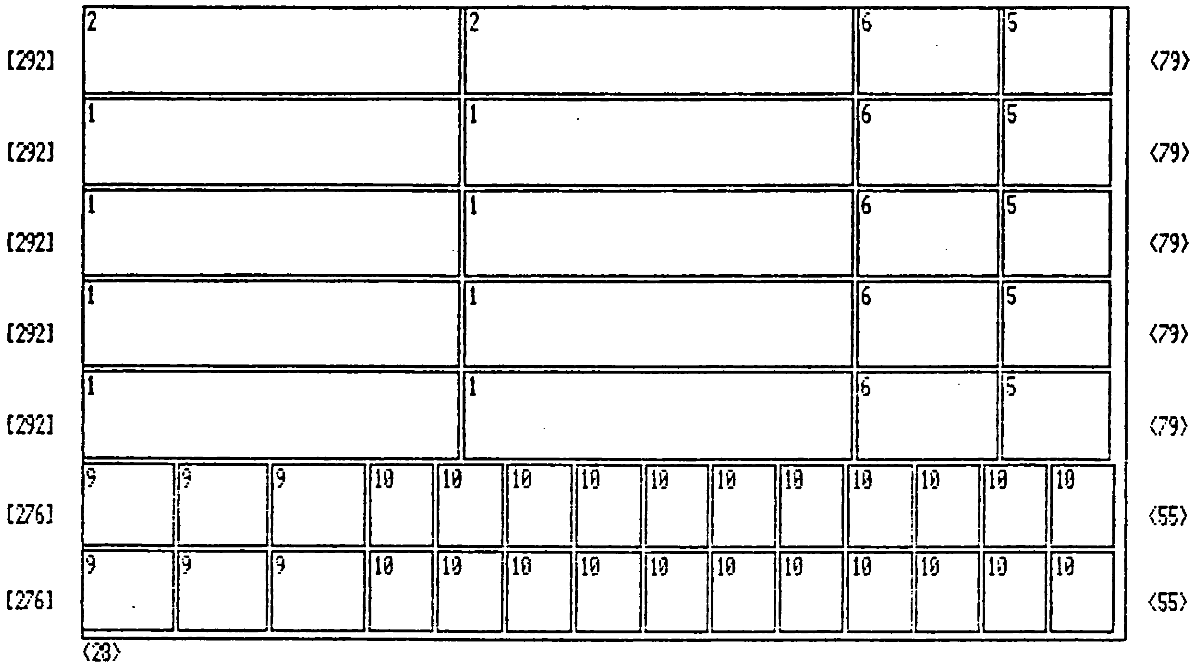
PATTERN NO. : 1.1. GOAL DIRECTION : P (1186)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 47. WASTE : 3.44 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
1.	PANEL 1.1.	1887	292	570	329	241
4.	PANEL 1.4.	832	292	420	423	- 3
6.	PANEL 1.6.	711	292	440	141	299
7.	PANEL 1.7.	437	292	260	282	- 22
8.	PANEL 1.8.	675	276	365	376	- 11
9.	PANEL 1.9.	475	276	635	470	165

PATTERN NO. : 2.1. GOAL DIRECTION : P (1616)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 31. WASTE : 4.72 %

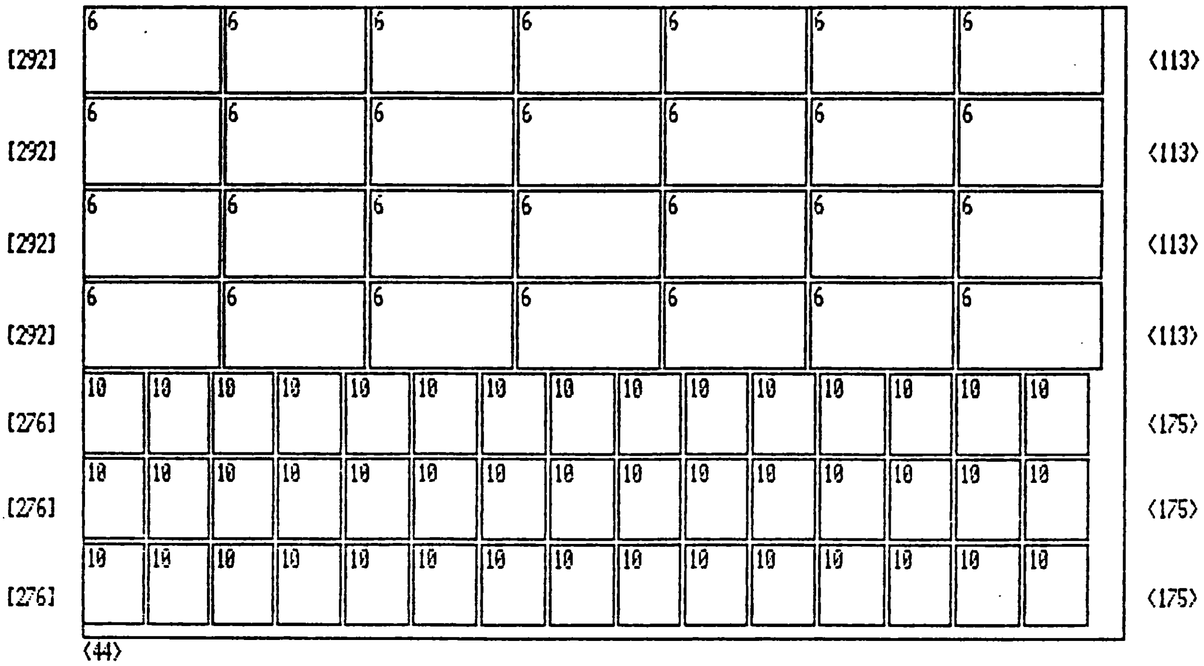


No.	Description / Code	Length	Width	No.Req.	No.Cut	RO.
2.	PANEL 1.2.	1887	292	50	62	- 12
6.	PANEL 1.6.	711	292	440	155	144
5.	PANEL 1.5.	541	292	150	155	- 5
1.	PANEL 1.1.	1887	292	570	248	- 7
9.	PANEL 1.9.	475	276	635	186	- 21
10.	PANEL 1.10.	325	276	880	682	198

D

PATTERN NO. : 3.1. GOAL DIRECTION : P (1467)

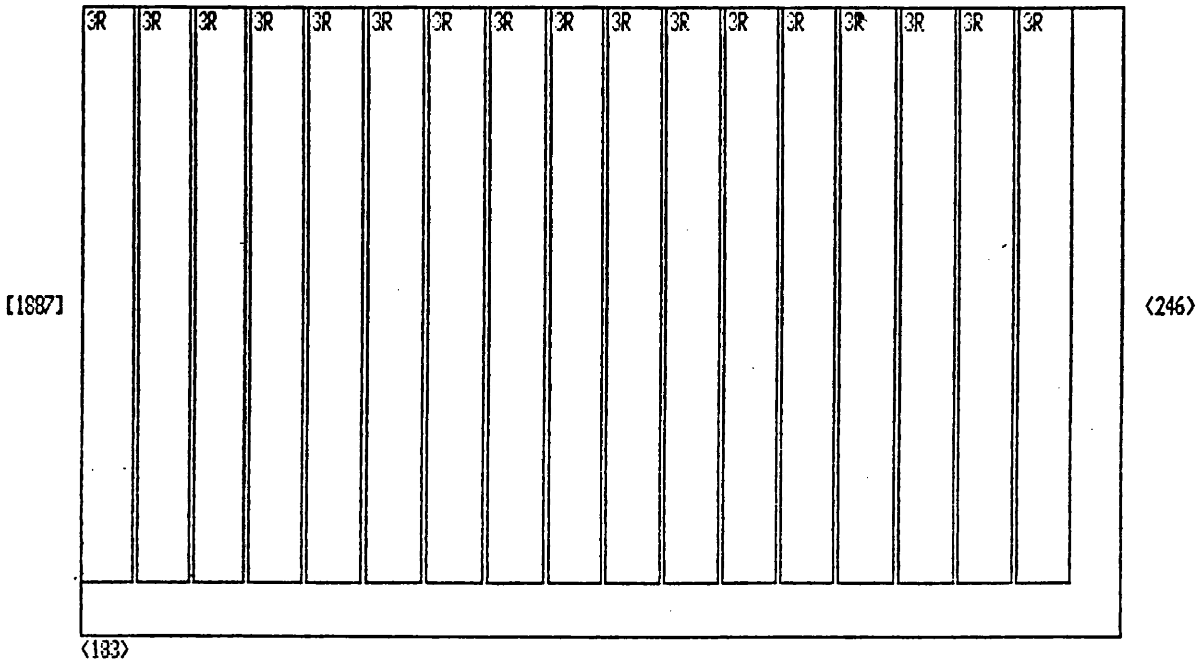
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 6. WASTE : 7.06 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
6.	PANEL 1.6.	711	292	440	168	- 24
10.	PANEL 1.10.	325	276	880	270	- 72

E

PATTERN NO. : 4.1. GOAL DIRECTION : P (830)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 3. WASTE : 14.64 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
3.	PANEL 1.3.	1887	282	50	51	- 1

F

SUMMARY	M2	M3	%/P	%/B
PANELS	848.7	12.73	100.0	92.0
EXTRA	36.8	.55	4.3	4.0
SHEETS	922.1	13.83	108.6	100.0
WASTE	36.6	.55	4.3	4.0

SHEET USAGE
87 ◆ 5120 X 2070
LAYOUT(0-4)? 1

OPTICUT 110683 TEST #2

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	1887	292	570	1	585	15	322.3	4.84	PANEL
2	1887	292	50	2	50	0	27.6	.41	PANEL
3	1887	282	50	3	50	0	26.6	.40	PANEL
4	832	292	420	4	432	12	105.0	1.57	PANEL
5	541	292	150	5	155	5	24.5	.37	PANEL
6	711	292	440	6	468	28	97.2	1.46	PANEL
7	437	292	260	7	270	10	34.5	.52	PANEL
8	675	276	365	8	412	47	76.8	1.15	PANEL
9	475	276	635	9	683	48	89.5	1.34	PANEL
10	325	276	880	10	910	30	81.6	1.22	PANEL
100	5120	2070	9999	12	87	-9912	922.1	13.83	PANEL

```
LINE/PLAN DEPENDENCE
  1: . . 4 . 6 7 . . .
  2: . 3 4 . . . . . .
  3: . 3 . . . . . . .
  4: . . 4 . . . . . .
  5: . . . 5 6 . . . .
  6: . . 4 . 6 . 8 9 .
  7: . . . . . 7 . . .
  8: 1 . 4 5 6 7 8 9 .
  9: . . 4 5 6 7 8 910
 10: . . . . . . . .10
100: 1 3 4 5 6 7 8 910
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 4
```

```
OPTICUT 110683  TEST #2

PLAN 711  5.3 % SAW 1 SHEETS   1 ◆ 5120 X 2070 X 15.0   10.6 M2    .

  :-----------------------------------------------------------:
  :276◆18  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  :: (62)
  : X675:  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
  :  ◆3 :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
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  :-----------------------------------------------------------:
  :-----------------------------------------------------------:
 (30)


 L/N LENGTH WIDTH  REQ IDENT   CUT      M2      M3 DESCRIPTION
   8   675   276   365     8    54    10.1     .15 PANEL

OPTICUT 110683  TEST #2

PLAN 713 15.5 % SAW 1 SHEETS   5 ◆ 5120 X 2070 X 15.0   53.0 M2    .

  :-----------------------------------------------------------:
  :292◆7:   :  :   :  :   :282◆10:  :  :   :  :   :  :  :   :X: (171)
  : X1887   :  :   :  :   : X1887:  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
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  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :  PANEL   :  :   :  :   :  :  PANEL  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :  :  :   :  :   :  :   :  :   :  :  :   :  :   :  :  :   :X:
  :-----------------------------------------------------------:
  :XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
  :-----------------------------------------------------------:
 (178)


 L/N LENGTH WIDTH  REQ IDENT   CUT      M2      M3 DESCRIPTION
   2  1887   292    50     2    35    19.3     .29 PANEL
   3  1887   282    50     3    50    26.6     .40 PANEL
```

```
PLAN 714  2.6 %.SAW 1 SHEETS  24 ◆ 5120 X 2070 X 15.0  254.4 M2

:-----------------------------------------------------------:
:475◆5     PANEL:     :     :675◆4  :    PANEL      :       : (0)
:-X276------------------------X276--------------------------:
:711    :832◆3    :         :        :1887                  : (1)
:-X292--:-X292-----------------------:-X292-----------------:
:  ◆6   :  ◆6     :         :        :  ◆6                  :
:       :         :         :        :                      :
:-------:----------------------------:----------------------:
:       :         :         :        :                      :
:       :         :         :        :                      :
:PANEL--:----------PANEL-------------:-------PANEL----------:
:       :         :         :        :                      :
:       :         :         :        :                      :
:-------:----------------------------:----------------------:
:       :         :         :        :                      :
:       :         :         :        :                      :
:-------:----------------------------:----------------------:
:       :         :         :        :                      :
:       :         :         :        :                      :
:-----------------------------------------------------------:
:-----------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	570	1	129	71.1	1.07	PANEL
2	1887	292	50	2	15	8.3	.12	PANEL
4	832	292	420	4	432	105.0	1.57	PANEL
6	711	292	440	6	144	29.9	.45	PANEL
8	675	276	365	8	96	17.9	.27	PANEL
9	475	276	635	9	120	15.7	.24	PANEL

OPTICUT 110683 TEST #2

```
PLAN 715  3.5 % SAW 1 SHEETS   1 ◆ 5120 X 2070 X 15.0   10.6 M2

:-----------------------------------------------------------:
:292◆17   :  :   :  :   :  :   :  :   :  :   :  :   :  :   :: (71)
: X541:   :  :   :  :   : PANEL:  :   :  :   :  :   :  :   ::
:  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::
:  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::
:-----------------------------------------------------------:
:276◆18  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  :: (62)
: X675:  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  PANEL  :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:-----------------------------------------------------------:
:475◆5     :    :     :     :675◆4  :       :       :       : (0)
:-X276----------------------:-X276--------------------------:
:  ◆3:     :    :     :     :  ◆3   :       :       :       :
:    :     PANEL:     :     :       :    PANEL      :       :
:---------------------------:-------------------------------:
:    :     :    :     :     :       :       :       :       :
:    :     :    :     :     :       :       :       :       :
:-----------------------------------------------------------:
:-----------------------------------------------------------:
(1)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	541	292	150	5	17	2.7	.04	PANEL
8	675	276	365	8	30	5.6	.08	PANEL
9	475	276	635	9	15	2.0	.03	PANEL

I

PLAN 716   3.8 % SAW 1 SHEETS   23 ◆ 5120 X 2070 X 15.0   243.8 M2

```
:---------------------------------------------------------------------:
:675◆4   :     PANEL        :           :475◆5      PANEL:      :      : (0)
:-X276-------------------------------X276-----------------------------:
:541   :711     :1887◆2                       :                        :: (74
:-X292:-X292--:-X292--------------------------------------------------::
:   ◆6 :   ◆6  :   ◆6                         :                        ::
:      :       :                              :                        ::
:-----:-------:-------------------------------------------------------::
:      :       :                              :                        ::
:      :       :                              :                        ::
PANEL-:PANEL--:------------------PANEL--------------------------------::
:      :       :                              :                        ::
:      :       :                              :                        ::
:-----:-------:-------------------------------------------------------::
:      :       :                              :                        ::
:      :       :                              :                        ::
:-----:-------:-------------------------------------------------------::
:      :       :                              :                        ::
:      :       :                              :                        ::
:---------------------------------------------------------------------:
:---------------------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	570	1	276	152.1	2.28	PANEL
5	541	292	150	5	138	21.8	.33	PANEL
6	711	292	440	6	138	28.7	.43	PANEL
8	675	276	365	8	92	17.1	.26	PANEL
9	475	276	635	9	115	15.1	.23	PANEL

OPTICUT 110683   TEST #2

PLAN 717   2.8 % SAW 1 SHEETS   15 ◆ 5120 X 2070 X 15.0   159.0 M2

```
:---------------------------------------------------------------------:
:475◆5      PANEL:        :       :675◆4   :     PANEL        :        : (0)
:-X276---------------------------X276---------------------------------:
:437◆3      :        :1887◆2                  :                        : (10)
:-X292----------:-X292------------------------------------------------:
:   ◆6:     :    :   ◆6                       :                        :
:       :     :    :                          :                        :
:--------------:------------------------------------------------------:
:       :     :    :                          :                        :
:       :     :    :                          :                        :
:---PANEL-------:------------------PANEL------------------------------:
:       :     :    :                          :                        :
:       :     :    :                          :                        :
:--------------:------------------------------------------------------:
:       :     :    :                          :                        :
:       :     :    :                          :                        :
:--------------:------------------------------------------------------:
:       :     :    :                          :                        :
:       :     :    :                          :                        :
:---------------------------------------------------------------------:
:---------------------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	570	1	180	99.2	1.49	PANEL
7	437	292	260	7	270	34.5	.52	PANEL
8	675	276	365	8	60	11.2	.17	PANEL
9	475	276	635	9	75	9.8	.15	PANEL

J

OPTICUT 110683   TEST #2

PLAN 718   4.7 % SAW 1 SHEETS   2 * 5120 X 2070 X 15.0   21.2 M2

```
:---------------------------------------------------------------:
:475*5     PANEL:      :     :675*4  :     PANEL     :          : (0)
:-X276-----------------------X276-------------------------------:
:711*7  :       :        :       :        :       :          :X: (108)
:-X292--------------------------------------------------------:X:
:  *6   :       :        :       :        :       :          :X:
:       :       :        :       :        :       :          :X:
:-------------------------------------------------------------:X:
:       :       :        :       :        :       :          :X:
:       :       :        :       :        :       :          :X:
:-------------------------PANEL-------------------------------:X:
:       :       :        :       :        :       :          :X:
:       :       :        :       :        :       :          :X:
:-------------------------------------------------------------:X:
:       :       :        :       :        :       :          :X:
:       :       :        :       :        :       :          :X:
:-------------------------------------------------------------:X:
:       :       :        :       :        :       :          :X:
:       :       :        :       :        :       :          :X:
:---------------------------------------------------------------:
:---------------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	711	292	440	6	84	17.4	.26	PANEL
8	675	276	365	8	8	1.5	.02	PANEL
9	475	276	635	9	10	1.3	.02	PANEL

OPTICUT 110683   TEST #2

PLAN 719   5.0 % SAW 1 SHEETS   6 * 5120 X 2070 X 15.0   63.6 M2

```
:---------------------------------------------------------------:
:292*17  :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::: (71)
: X711:  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :::
:  :  :  :  :   :  :   : PANEL:  :   :  :   :  :   :  :   :::
:  :  :  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :::
:  :  :  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :::
:---------------------------------------------------------------:
:675*4  :       :       :       :475*5     :    :     :         : (0)
:-X276--------------------------:-X276--------------------------:
:  *3   :       :       :       :   *3:    :    :     :         :
:       :   PANEL       :       :     :    PANEL:     :         :
:-------------------------------:-------------------------------:
:       :       :       :       :     :    :    :     :         :
:       :       :       :       :     :    :    :     :         :
:---------------------------------------------------------------:
:  :  :  :   :  :  :   :  :  :   :  :  :   :  :  :   :  :  :    :
:276*18  :   :  :  :   :  :  :   :  :  :   :  :  :   :  :  ::: (62)
: X475:  :   :  :  :   :  PANEL  :  :  :   :  :  :   :  :  :::
:  :  :  :   :  :  :   :  :  :   :  :  :   :  :  :   :  :  :::
:---------------------------------------------------------------:
:---------------------------------------------------------------:
(31)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	711	292	440	6	102	21.2	.32	PANEL
8	675	276	365	8	72	13.4	.20	PANEL
9	475	276	635	9	198	26.0	.39	PANEL

OPTICUT 110683 · TEST #2

PLAN 720 4.6 % SAW 1 SHEETS 10 ♦ 5120 X 2070 X 15.0 106.0 M2   1

```
 :--------------------------------------------------------------:
 :276♦18  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  :: (62)
 : X325:  :   :  :  ;   :  :  :   :  :  :  :   :  :  :   :  ::
 :--♦2--------------------PANEL---------------------------------::
 :  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
 :  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
 :--------------------------------------------------------------:
 :325♦11:   :   :   :   :   :   :   :  :   :475♦3:     :     :: (50)
 :-X276-------------------------------------:-X276-----------::
 :  ♦5  :   :   :   :   :   :   :   :  :   :  ♦5 :     :     ::
 :  :   :   :   :   :   :   :   :   :  :   :     :     :     ::
 :------------------------------------------:-----------------::
 :  :   :   :   :  PANEL:   :   :   :  :   :    PANEL  :     ::
 :  :   :   :   :   :   :   :   :   :  :   :     :     :     ::
 :------------------------------------------:-----------------::
 :  :   :   :   :   :   :   :   :   :  :   :     :     :     ::
 :------------------------------------------:-----------------::
 :  :   :   :   :   :   :   :   :   :  :   :     :     :     ::
 :  :   :   :   :   :   :   :   :   :  :   :     :     :     ::
 :--------------------------------------------------------------:
 :--------------------------------------------------------------:
(5)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
9	475	276	635	9	150	19.7	.29	PANEL
10	325	276	880	10	910	81.6	1.22	PANEL

OPTICUT 110683 TEST #2

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTI[O]
1	1887	292	570	1	585	15	322.3	4.84	PANEL
2	1887	292	50	2	50	0	27.6	.41	PANEL
3	1887	282	50	3	50	0	26.6	.40	PANEL
4	832	292	420	4	432	12	105.0	1.57	PANEL
5	541	292	150	5	155	5	24.5	.37	PANEL
6	711	292	440	6	468	28	97.2	1.46	PANEL
7	437	292	260	7	270	10	34.5	.52	PANEL
8	675	276	365	8	412	47	76.8	1.15	PANEL
9	475	276	635	9	683	48	89.5	1.34	PANEL
10	325	276	880	10	910	30	81.6	1.22	PANEL
100	5120	2070	9999	12	87	-9912	922.1	13.83	PANEL

```
LINE/PLAN DEPENDENCE
  1: . . 4 . 6 7 . . .
  2: . 3 4 . . . . . .
  3: . 3 . . . . . . .
  4: . . 4 . . . . . .
  5: . . . 5 6 . . . .
  6: . . 4 . 6 . 8 9 .
  7: . . . . . 7 . . .
  8: 1 . 4 5 6 7 8 9 .
  9: . . 4 5 6 7 8 910
 10: . . . . . . . . .10
100: 1 3 4 5 6 7 8 910
WHAT NEXT? 1
1-INPUT DATA TO LIB.FILE
 L/N LENGTH WIDTH  REQ IDENT   CUT P/MOD DESCRIPTION
  1?
```

Test No. 2.

number of panel orders 6.

[illegible] Systems (c) POPS Monday 18th Apr 1983

PANEL REQUIREMENTS

NO.	PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
[illegible]	PANEL 10.1.	589	589	15	N	Y	110	10
[illegible]	PANEL 10.2.	431	546	15	N	Y	520	10
[illegible]	PANEL 10.3.	431	396	15	N	Y	110	10
[illegible]	PANEL 10.4.	431	431	15	N	Y	220	10
[illegible]	PANEL 10.5.	444	396	15	N	Y	230	10
[illegible]	PANEL 10.6.	444	556	15	N	Y	200	10

A

[illegible]attern Systems (c) POPS Monday 18th Apr 1983

BOARD AVAILABILITY

NO.	BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
1.	BOARD 1.	5120	2070	15	30000

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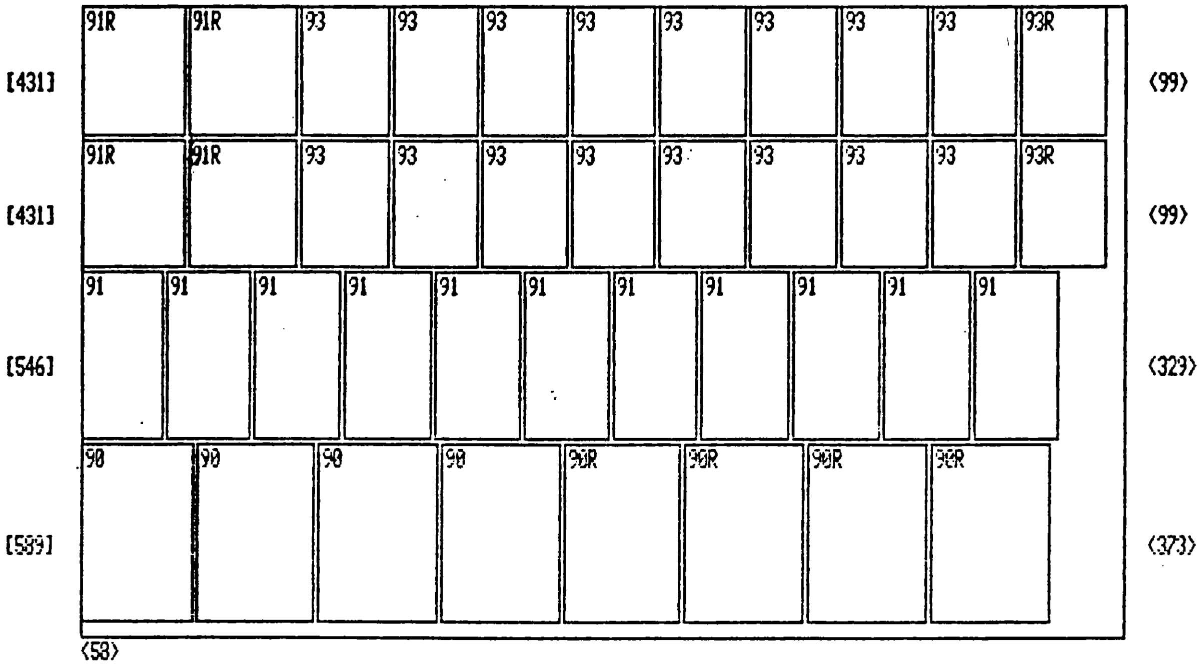
CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m^2)	% Panels	% Boards
Panel requirements :	309.92	100.29	86.08
Extras produced :	21.09	6.82	5.85
Board area used :	360.34	116.61	100.09
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	5.99	1.93	1.66
Edge trim :	0.00	0.00	0.00
Additional waste :	23.34	7.55	6.48
WASTAGE :	29.33	9.49	8.14

PATTERN NO. : 1.1. GOAL DIRECTION : P (1081)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 14. WASTE : 8.95 %

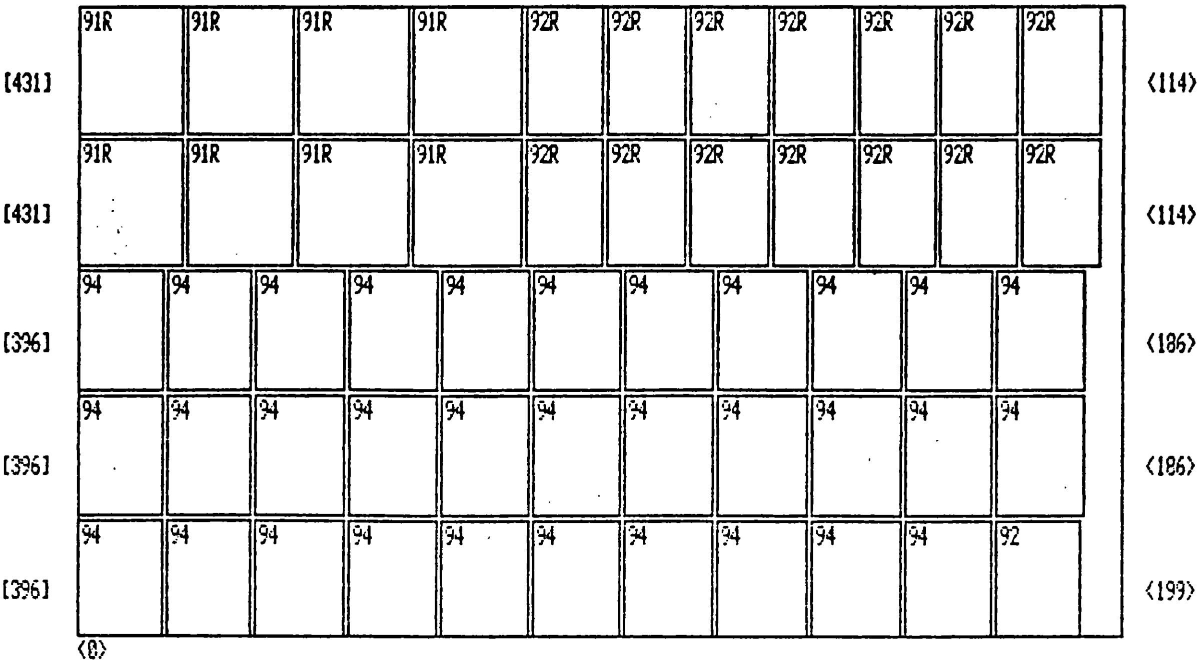


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
91.	PANEL 10.2.	431	546	520	210	310
93.	PANEL 10.4.	431	431	220	252	- 32
90.	PANEL 10.1.	589	589	110	112	- 2

c

PATTERN NO. : 2.1. GOAL DIRECTION : P (1163)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 8. WASTE : 4.99 %

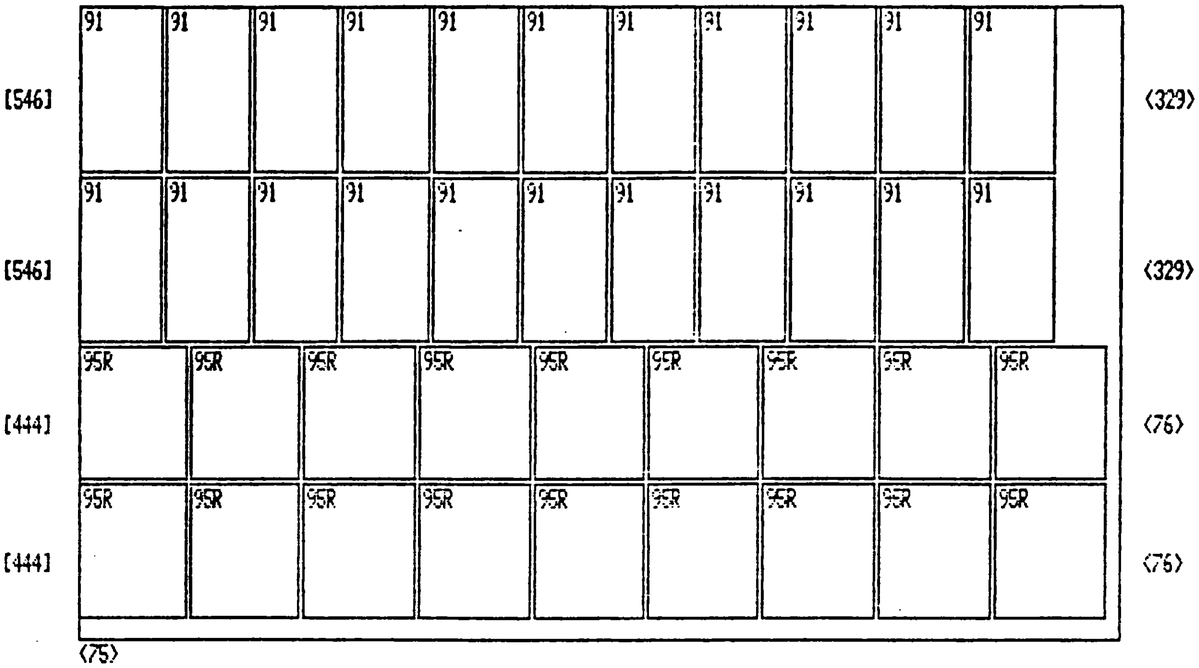


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
91.	PANEL 10.2.	431	546	520	64	246
92.	PANEL 10.3.	431	396	110	120	- 10
94.	PANEL 10.5.	444	396	230	256	- 26

D

PATTERN NO. : 3.1. GOAL DIRECTION : P (1330)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 12. WASTE : 9.22 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
91.	PANEL 10.2.	431	546	520	264	- 18
95.	PANEL 10.6.	444	556	200	216	- 16

```
SUMMARY        M2       M3      %/P      %/B
PANELS      292.9     4.39    100.0     89.2
EXTRA        10.2      .15      3.5      3.1
SHEETS      328.6     4.93    112.2    100.0
WASTE        25.4      .38      8.7      7.7
OFFAL        11.0      .16      3.8      3.3

SHEET USAGE
  31 * 5120 X 2070
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 1
OPTICUT 110683  TEST # 3.

 L/N LENGTH WIDTH  REQ IDENT    CUT DIFF.        M2        M3 DESCRIPTION
   1    589   589  110     1    112     2      38.9       .58 PANEL
   2    431   546  520     2    539    19     126.8      1.90 PANEL
   3    431   396   10     3     12     2       2.0       .03 PANEL
   4    431   431  220     4    222     2      41.2       .62 PANEL
   5    444   396  230     5    242    12      42.5       .64 PANEL
   6    444   556  200     6    209     9      51.6       .77 PANEL
 100   5120  2070 9999    12     31 -9968     328.6      4.93 PANEL
LINE/PLAN DEPENDENCE
   1: 1 . . 4 . .
   2: . 2 3 4 . 6
   3: 1 . . . 5 .
   4: 1 . 3 4 5 .
   5: . 2 . . 5 6
   6: . . 3 . . 6
 100: 1 2 3 4 5 6
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 4
```

F

```
OPTICUT 110683  TEST # 3.  .

PLAN 721  7.2 % SAW 1 SHEETS   1 * 5120 X 2070 X 15.0   10.6 M2    .1

 :------------------------------------------------------------------:
 :589*8:      :       :       :       :       :       :      :XXXX: (368)
 :  X589:     :       :       :       :       :       :      :XXXX:
 :   *2 :     :       :       :       :       :       :      :XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :-----------------------PANEL-------------------------------:XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :      :     :       :       :       :       :       :      :XXXX:
 :------------------------------------------------------------------:
 :396*4    :    :    :431*8:    :    :    :    :    :    :    :: (28)
 : X431    :    :    : X431:    :    :    :    :    :    :    ::
 :  *2     :    :    :  *2 :    :    :    :    :    :    :    ::
 :-----PANEL--------:-----------------PANEL-----------------------::
 :   :     :    :    :     :    :    :    :    :    :    :    ::
 :   :     :    :    :     :    :    :    :    :    :    :    ::
 :   :     :    :    :     :    :    :    :    :    :    :    ::
 :------------------------------------------------------------------:
 :------------------------------------------------------------------:
(10)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	589	589	110	1	16	5.6	.08	PANEL
3	431	396	10	3	8	1.4	.02	PANEL
4	431	431	220	4	16	3.0	.04	PANEL
--	368	589	2	--	2	.4	.01	OFFAL

```
OPTICUT 110683  TEST # 3.

PLAN 722  9.3 % SAW 1 SHEETS   9 * 5120 X 2070 X 15.0   95.4 M2    1.43

 :------------------------------------------------------------------:
 :444*11   :    :     :    PANEL:    :     :    :    :     :X: (181)
 : X396    :    :     :    :    :    :     :    :    :     :X:
 :------------------------------------------------------------------:
 :431*11   :    :    :    :    :    :     :    :    :     :XXX: (324)
 : X546    :    :    :    :    :    :     :    :    :     :XXX:
 :  *3:    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :-------------------------------------------------------------:XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :   PANEL:   :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :-------------------------------------------------------------:XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :    :    :    :    :    :    :    :     :    :    :     :XXX:
 :------------------------------------------------------------------:
 :------------------------------------------------------------------:
(16)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	431	546	520	2	297	69.9	1.05	PANEL
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
--	324	546	27	--	[illegible]	[illegible]	[illegible]	OFFAL

9

```
OPTICUT 110683  TEST # 3.

PLAN 723  9.1 % SAW 1 SHEETS   5 * 5120 X 2070 X 15.0   53.0 M2     .79

  :--------------------------------------------------------------------:
  :444*11    :    :     :    :    :    :     :    :    :          :X: (181)
  : X556     :    :     :    :    :    :     :    :    :          :X:
  :  *2:     :    :     :    :    :    :     :    :    :          :X:
  :    :     :    :     :    :    :    :     :    :    :          :X:
  :-------------------------PANEL----------------------------------:X:
  :    :     :    :     :    :    :    :     :    :    :          :X:
  :    :     :    :     :    :    :    :     :    :    :          :X:
  :    :     :    :     :    :    :    :     :    :    :          :X:
  :    :     :    :     :    :    :    :     :    :    :          :X:
  :--------------------------------------------------------------------:
  :546*2:     :431*9:     :    :    :    :    :    :     :    :: (94)
  : X431:     : X431:     :    :    :    :    :    :     :    ::
  :  *2 :     :  *2 :     :    :    :    :    :    :     :    ::
  :--PANEL----:--------------------PANEL------------------------::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :--------------------------------------------------------------------:
  :                                                                    :
  :--------------------------------------------------------------------:
 (76)

 L/N LENGTH WIDTH  REQ IDENT   CUT       M2       M3 DESCRIPTION
   2    431   546  520     2    20      4.7      .07 PANEL
   4    431   431  220     4    90     16.7      .25 PANEL
   6    444   556  200     6   110     27.2      .41 PANEL

OPTICUT 110683  TEST # 3.

PLAN 724  7.8 % SAW 1 SHEETS   6 * 5120 X 2070 X 15.0   63.6 M2     .95

  :--------------------------------------------------------------------:
  :546*2:     :431*9:     :    :    :    :    :    :     :    :: (94)
  : X431:     : X431:     :    :    :    :    :    :     :    ::
  :  *2 :     :  *2 :     :    :    :    :    :    :     :    ::
  :--PANEL----:--------------------PANEL------------------------::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :     :     :     :     :    :    :    :    :    :     :    ::
  :--------------------------------------------------------------------:
  :589*8:      :      :      :      :      :      :     :XXXX: (368)
  : X589:      :      :      :      :      :      :     :XXXX:
  :  *2 :      :      :      :      :      :      :     :XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :----------------------PANEL--------------------------:XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :     :      :      :      :      :      :      :     :XXXX:
  :--------------------------------------------------------------------:
  :--------------------------------------------------------------------:
 (10)

 L/N LENGTH WIDTH  REQ IDENT   CUT       M2       M3 DESCRIPTION
   1    589   589  110     1   [illegible]  [illegible]  .5[illegible] PANEL
   2    431   546  520     2    24      5.6      .08 PANEL
 [illegible]  431   431  220     4   108     20.1      .30 PANEL
   -    368  [illegible]   12    --    12  [illegible]  .04 OFFAL
```

H

OPTICUT 110683 TEST # 3.

PLAN 725 7.0 % SAW 1 SHEETS   1 + 5120 X 2070 X 15.0   10.6 M2   .16

```
:------------------------------------------------------------:
:444+11  :    :     :    :    :    :     :    :    :     :X: (181)
: X396   :    :     :    :    :    :     :    :    :     :X:
:--+4-------------------------------------------------------:X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:-------------------------PANEL-----------------------------:X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:-----------------------------------------------------------:X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:------------------------------------------------------------:
:396+4   :    :   :431+8:    :    :    :    :    :    :    :: (28)
: X431PANEL   :   : X431:    :    :PANEL    :    :    :    ::
:  :   :    :   :     :    :    :    :    :    :    :    ::
:------------------------------------------------------------:
:------------------------------------------------------------:
(30)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
3	431	396	10	3	4	.7	.01	PANEL
4	431	431	220	4	8	1.5	.02	PANEL
5	444	396	230	5	44	7.7	.12	PANEL

OPTICUT 110683 TEST # 3.

PLAN 726 7.9 % SAW 1 SHEETS   9 + 5120 X 2070 X 15.0   95.4 M2   1.43

```
:------------------------------------------------------------:
:444+11  :    :     :    PANEL:    :     :    :    :     :X: (181)
: X396   :    :     :    :    :    :     :    :    :     :X:
:------------------------------------------------------------:
:431+11  :    :    :    :    :    :     :    :    :    :XXX: (324)
: X546   :    :    :    :    :    :     :    :    :    :XXX:
:  +2:   :    :    :    :    :    :     :    :    :    :XXX:
:   :    :    :    :    :    :    :     :    :    :    :XXX:
:-----------------------PANEL-----------------------------:XXX:
:   :    :    :    :    :    :    :     :    :    :    :XXX:
:   :    :    :    :    :    :    :     :    :    :    :XXX:
:   :    :    :    :    :    :    :     :    :    :    :XXX:
:   :    :    :    :    :    :    :     :    :    :    :XXX:
:------------------------------------------------------------:
:   :    :    :     :    :    :    :     :    :    :         :
:444+11  :    :     :    :    :    :     :    :    :     :X: (181)
: X556   :    :     :    PANEL:    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:   :    :    :     :    :    :    :     :    :    :     :X:
:------------------------------------------------------------:
:------------------------------------------------------------:
(6)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	431	546	520	2	198	46.6	.70	PANEL
5	444	[illegible]	[illegible]	5	99	17.4	.26	PANEL
6	444	556	200	6	99	24.4	.37	PANEL
--	324	546	18	--	18	3.2	[illegible]	OFFAL

I

Test No. 3.

number of panel orders 11.

ttern Systems (c) **POPS** Monday 18th Apr 1983

PANEL REQUIREMENTS

PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
PANEL 3.1.	607	430	15	N	Y	1000	10
PANEL 3.2.	907	430	15	N	Y	600	10
PANEL 3.3.	1007	430	15	N	Y	500	10
PANEL 3.4.	1207	430	15	N	Y	300	10
PANEL 3.5.	607	454	15	N	Y	500	10
PANEL 3.6.	907	454	15	N	Y	300	10
PANEL 3.7.	1007	454	15	N	Y	250	10
PANEL 3.8.	1207	454	15	N	Y	150	10
PANEL 3.9.	775	390	15	N	Y	600	10
PANEL 3.10.	975	390	15	N	Y	600	10
PANEL 3.11.	357	390	15	N	Y	1200	10

ttern Systems (c) **POPS** Monday 18th Apr 1983

BOARD AVAILABILITY

BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
BOARD 1.	5120	2070	15	30000

A

©Pattern Systems	POPS	Monday	18th Apr 1983

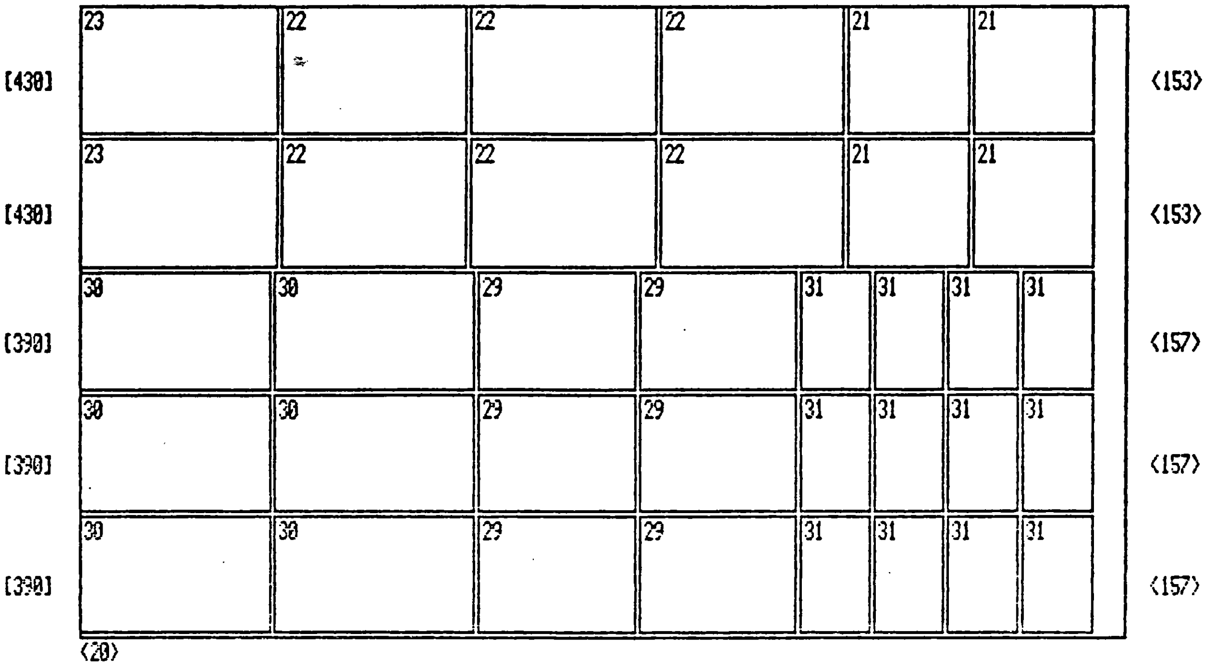
CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m^2)	% Panels	% Boards
Panel requirements :	1901.40	100.02	90.62
Extras produced :	26.95	1.41	1.28
Board area used :	2098.48	110.38	100.02
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	29.37	1.54	1.39
Edge trim :	0.00	0.00	0.00
Additional waste :	140.76	7.40	6.70
WASTAGE :	170.13	8.94	8.10

B

PATTERN NO. : 1.1. GOAL DIRECTION : P (1410)

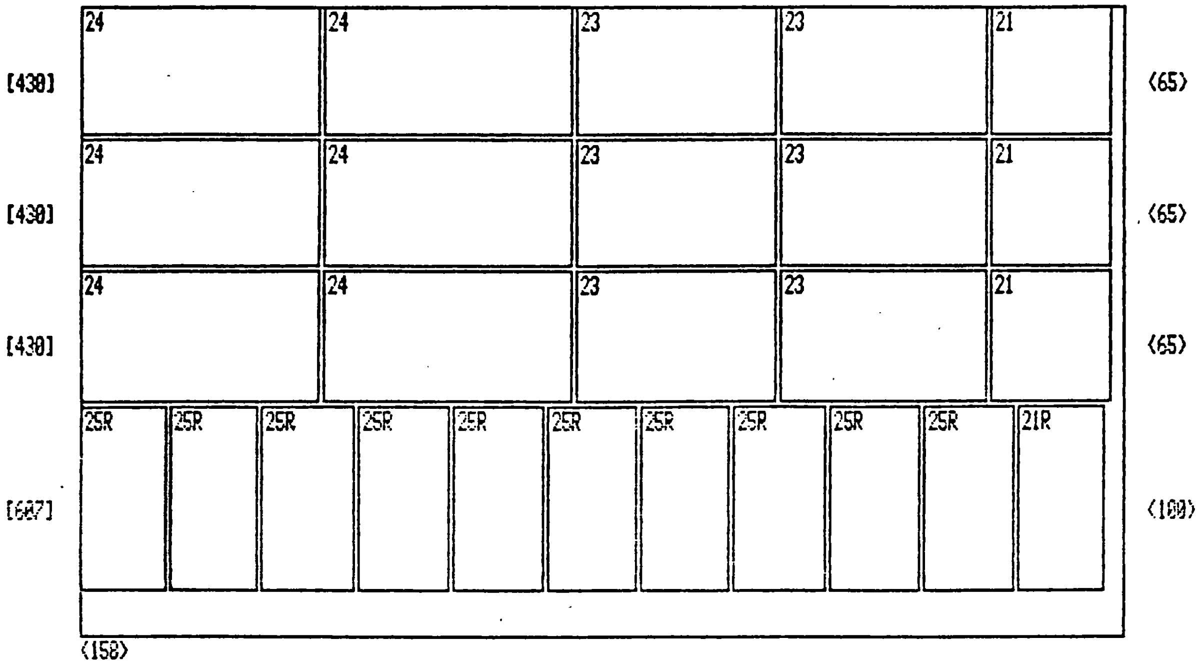
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 100. WASTE : 5.49 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
23.	PANEL 3.3.	1007	430	500	200	300
22.	PANEL 3.2.	907	430	600	600	0
21.	PANEL 3.1.	607	430	1000	400	600
30.	PANEL 3.10.	975	390	600	600	0
29.	PANEL 3.9.	775	390	600	600	0
31.	PANEL 3.11.	357	390	1200	1200	0

c

PATTERN NO. : 2.1. GOAL DIRECTION : P (1281)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 50. WASTE : 10.25 %

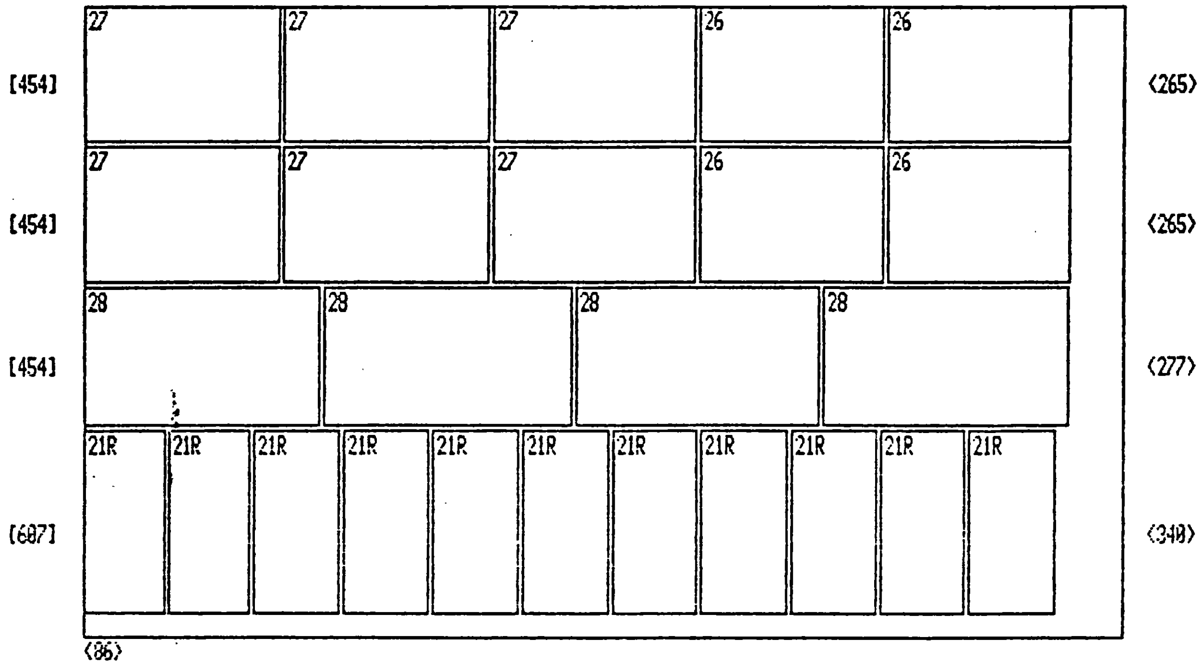


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
24.	PANEL 3.4.	1207	430	300	300	0
23.	PANEL 3.3.	1007	430	500	300	0
21.	PANEL 3.1.	607	430	1000	200	400
25.	PANEL 3.5.	607	454	500	500	0

D

PATTERN NO. : 3.1. GOAL DIRECTION : P (1301)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 42. WASTE : 10.80 %

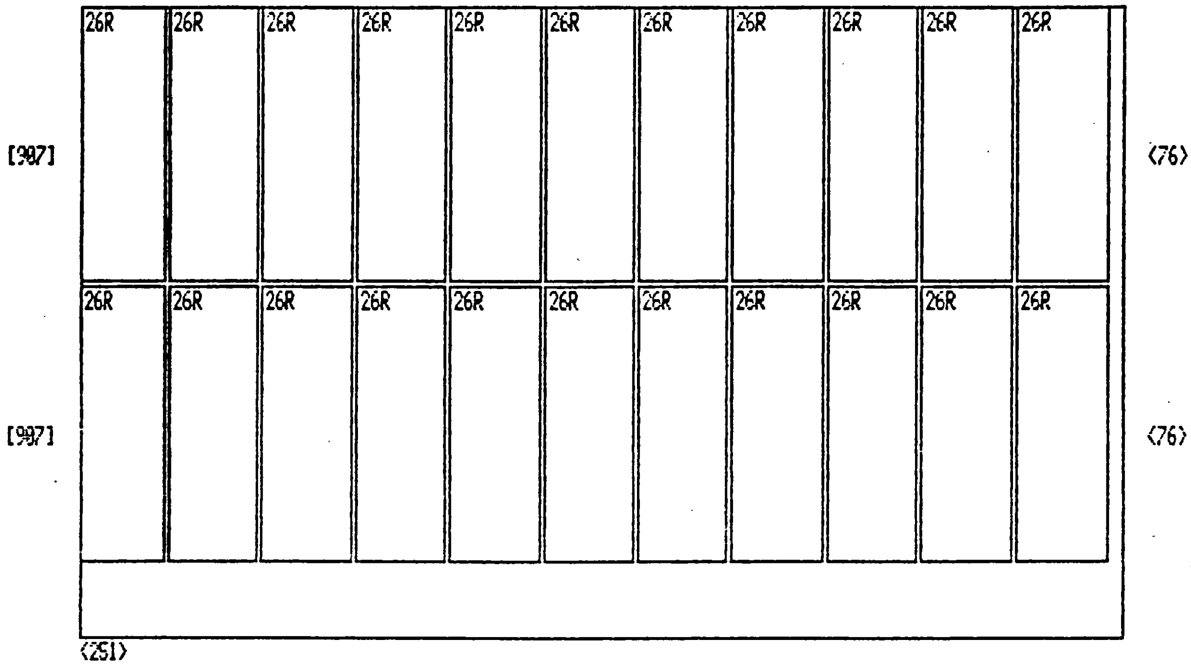


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
27.	PANEL 3.7.	1007	454	250	252	- 2
26.	PANEL 3.6.	907	454	300	168	132
28.	PANEL 3.8.	1207	454	150	168	- 18
21.	PANEL 3.1.	607	430	1000	462	- 62

E

PATTERN NO. : 4.1. GOAL DIRECTION : P (917)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 6. WASTE : 14.52 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
26.	PANEL 3.6.	907	454	300	132	0

F

SUMMARY	M2	M3	%/P	%/B
PANELS	1901.6	28.52	100.0	93.9
EXTRA	23.9	.36	1.3	1.2
SHEETS	2024.3	30.36	106.5	100.0
WASTE	98.8	1.48	5.2	4.9
OFFAL	30.0	.45	1.6	1.5

```
SHEET USAGE
 191 + 5120 X 2070
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 1
OPTICUT 110683  TEST #4
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	607	430	1000	1	1005	5	262.3	3.93	PANEL
2	907	430	600	2	610	10	237.9	3.57	PANEL
3	1007	430	500	3	500	0	216.5	3.25	PANEL
4	1207	430	300	4	304	4	157.8	2.37	PANEL
5	607	454	500	5	515	15	141.9	2.13	PANEL
6	907	454	300	6	301	1	123.9	1.86	PANEL
7	1007	454	250	7	253	3	115.7	1.73	PANEL
8	1207	454	150	8	156	6	85.5	1.28	PANEL
9	775	390	600	9	604	4	182.6	2.74	PANEL
10	975	390	600	10	614	14	233.5	3.50	PANEL
11	357	390	1200	11	1206	6	167.9	2.52	PANEL
100	5120	2070	9999	12	191	-9808	2024.3	30.36	PANEL

```
LINE/PLAN DEPENDENCE
  1: 1 2 . 4 . . 7 . 910 .
  2: . 2 3 4 5 . . . .10 .
  3: 1 2 . . . . 7 . . . .
  4: . . 3 . 5 6 . . . . .
  5: . . . 4 . 6 7 . 9 . .
  6: . . . . . 6 . 8 9 .11
  7: . . . . . . 7 . . . .
  8: . . . . . . . 8 . . .
  9: 1 . 3 4 . 6 . 8 . . .
 10: 1 2 3 4 5 6 . 8 .1011
 11: . 2 . . . . . . . .11
100: 1 2 3 4 5 6 7 8 91011
WHAT NEXT? 4
```

PLAN 691   3.4 % SAW 1 SHEETS   19 ◆ 5120 X 2070 X 15.0   201.4 M2   3.02 M3

```
 :---------------------------------------------------------------:
 :607◆5 :       :       :       :       :1007◆2      :           :: (36)
 :  X430 :      :       :       :       : X430       :           ::
 :   ◆2  :      :       :       :       :  ◆2        :           ::
 :--------------PANEL-------------------:--------PANEL-----------::
 :       :      :       :       :       :            :           ::
 :       :      :       :       :       :            :           ::
 :       :      :       :       :       :            :           ::
 :---------------------------------------------------------------:
 :775◆4    :         :         :        :975◆2         :         :: (40)
 :  X390   :         :         :        : X390         :         ::
 :--◆3----------------------------------:--◆3--------------------::
 :         :         :         :        :              :         ::
 :         :  PANEL            :        :        PANEL           ::
 :         :         :         :        :              :         ::
 :--------------------------------------:------------------------::
 :         :         :         :        :              :         ::
 :         :         :         :        :              :         ::
 :         :         :         :        :              :         ::
 :---------------------------------------------------------------:
 :---------------------------------------------------------------:
(15)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	190	49.6	.74	PANEL
3	1007	430	500	3	76	32.9	.49	PANEL
9	775	390	600	9	228	68.9	1.03	PANEL
10	975	390	600	10	114	43.3	.65	PANEL

OPTICUT 110683 TEST #4

PLAN 692   4.4 % SAW 1 SHEETS   63 ◆ 5120 X 2070 X 15.0   667.7 M2   10.02 M3

```
 :---------------------------------------------------------------:
 :390◆12  :   :    :    :PANEL   :    :    :    :    :    :XXXX: (380)
 : X357   :   :    :    :   :    :    :    :    :    :    :XXXX:
 :---------------------------------------------------------------:
 :357◆6  :PANEL   :   :    :975◆3       : PANEL     :            : (8)
 : X390  :   :    :   :    : X390       :           :            :
 :---------------------------------------------------------------:
 :           :                    :            :           :     :
 :1007◆2     :           :607◆2   :     :907◆2       :           :: (48)
 : X430      :           : X430   :     : X430       :           ::
 :  ◆3       :           :  ◆3    :     :  ◆3        :           ::
 :-----------------------:-------------:-------------------------::
 :           :           :        :     :            :           ::
 :      PANEL            :    PANEL     :        PANEL           ::
 :           :           :        :     :            :           ::
 :-----------------------:-------------:-------------------------::
 :           :           :        :     :            :           ::
 :           :           :        :     :            :           ::
 :           :           :        :     :            :           ::
 :---------------------------------------------------------------:
 :---------------------------------------------------------------:
(8)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	378	99.7	1.48	PANEL
2	907	430	600	2	378	147.4	2.21	PANEL
[illegible]	1007	430	500	3	378	163.7	2.46	PANEL
10	975	390	600	10	189	71.9	1.08	PANEL
11	357	390	1200	11	1134	157.9	2.37	PANEL

H

```
PLAN 693  5.3 % SAW 1 SHEETS  16 + 5120 X 2070 X 15.0  169.6 M2   2.54

  :---------------------------------------------------------------------:
  :975+2      :           :775+4   :        :        :        :: (40)
  : X390      :           : X390   :        :        :        ::
  :---+3------------------:---+3--------------------------------::
  :           :           :        :        :        :        ::
  :      PANEL            :        :     PANEL       :        ::
  :           :           :        :        :        :        ::
  :-----------------------:-------------------------------------::
  :           :           :        :        :        :        ::
  :           :           :        :        :        :        ::
  :           :           :        :        :        :        ::
  :---------------------------------------------------------------------:
  :1207          :907+4     :          :          :          :XX: (260)
  : X430         : X430     :          :          :          :XX:
  :  +2          :  +2      :          :          :          :XX:
  :---PANEL------:-----------------PANEL---------------------:XX:
  :              :          :          :          :          :XX:
  :              :          :          :          :          :XX:
  :              :          :          :          :          :XX:
  :---------------------------------------------------------------------:
  :---------------------------------------------------------------------:
 (15)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	907	430	600	2	128	49.9	.75	PANEL
4	1207	430	300	4	32	16.6	.25	PANEL
9	775	390	600	9	192	58.0	.87	PANEL
10	975	390	600	10	96	36.5	.55	PANEL
--	260	430	32	--	32	3.6	.05	OFFAL

OPTICUT 110683 TEST #4

```
PLAN 694  4.8 % SAW 1 SHEETS   9 + 5120 X 2070 X 15.0   95.4 M2   1.43

  :---------------------------------------------------------------------:
  :775+4   :     PANEL       :        :975+2  PANEL          :: (40)
  : X390   :        :        :        : X390        :        ::
  :---------------------------------------------------------------------:
  :607+2 :      :907+4     :          :          :          :XX: (248)
  : X430PANEL   : X430     :     PANEL           :          :XX:
  :      :      :          :          :          :          :XX:
  :---------------------------------------------------------------------:
  :    :    :    :    :    :    :    :    :    :    :    :
  :454+11   :    :    :    :    :    :    :    :    :    :: (71)
  : X607    :    :    :    :    :    :    :    :    :    ::
  :  +2:    :    :    :    :    :    :    :    :    :    ::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :-------------------------PANEL-------------------------------::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :    :    :    :    :    :    :    :    :    :    :    ::
  :---------------------------------------------------------------------:
  :---------------------------------------------------------------------:
 (16)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	18	4.7	.07	PANEL
2	907	430	600	2	36	14.0	.21	PANEL
[illegible]	607	454	[illegible]	5	[illegible]	54.6	.82	PANEL
9	775	390	[illegible]	9	[illegible]	10.9	.16	PANEL
10	975	390	600	10	18	6.8	.10	PANEL

I

PLAN 695 7.3 % SAW 1 SHEETS 4 ◆ 5120 X 2070 X 15.0 42.4 M2 .64

```
:-----------------------------------------------------------------:
:975◆5     :          :          :          :          :XX: (220)
: X390     :          :          :          :          :XX:
:--◆3--------------------------------------------------:XX:
:          :          :          :          :          :XX:
:          :          : PANEL    :          :          :XX:
:          :          :          :          :          :XX:
:------------------------------------------------------:XX:
:          :          :          :          :          :XX:
:          :          :          :          :          :XX:
:          :          :          :          :          :XX:
:-----------------------------------------------------------------:
:1207          :907◆4      :          :          :          :XX: (260)
: X430         : X430      :          :          :          :XX:
:  ◆2          :  ◆2       :          :          :          :XX:
:---PANEL-----:-----------------PANEL--------------------:XX:
:              :           :          :          :          :XX:
:              :           :          :          :          :XX:
:              :           :          :          :          :XX:
:-----------------------------------------------------------------:
:-----------------------------------------------------------------:
(15)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	907	430	600	2	32	12.5	.19	PANEL
4	1207	430	300	4	8	4.2	.06	PANEL
10	975	390	600	10	60	22.8	.34	PANEL
--	260	430	8	--	8	.9	.01	OFFAL

OPTICUT 110683 TEST #4

PLAN 696 7.3 % SAW 1 SHEETS 24 ◆ 5120 X 2070 X 15.0 254.4 M2 3.82

```
:-----------------------------------------------------------------:
:775◆4   :    PANEL        :        :975◆2  PANEL          :: (40)
: X390   :      :          :        : X390       :         ::
:-----------------------------------------------------------------:
:430◆11  :   :   :   :   :   :   :   :   :   :XXX: (335)
: X1207  :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   PANEL:  :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:    :   :   :   :   :   :   :   :   :   :   :XXX:
:-----------------------------------------------------------------:
:       :              :          :          :          :
:607◆2  :       :907◆4 :          :          :          :XX: (248)
: X454PANEL     : X454 :          PANEL      :          :XX:
:       :       :      :          :          :          :XX:
:-----------------------------------------------------------------:
:-----------------------------------------------------------------:
(4)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
4	1207	430	300	4	264	137.0	2.06	PANEL
5	607	454	500	5	48	13.2	.20	PANEL
6	907	454	300	6	96	39.5	.59	PANEL
9	775	390	600	9	96	29.0	.44	PANEL
10	975	390	600	10	48	15.3	.27	PANEL

J

PLAN 697 3.6 % SAW 1 SHEETS 23 ◆ 5120 X 2070 X 15.0 243.8 M2 3.6

```
:--------------------------------------------------------------------------:
:454◆11  :      :    :     :    :    :     :    :     :    ::(71)
: X607   :      :    :   PANEL :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:--------------------------------------------------------------------------:
:454◆11  :      :    :     :    :    :     :    :     :    ::(71)
: X1007  :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :   PANEL :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:--------------------------------------------------------------------------:
:      :      :      :      :              :          ::
:607◆5 :      :      :      :       :1007◆2    :          ::(36)
: X430 :      :PANEL :      :       : X430  PANEL         ::
:      :      :      :      :       :          :          ::
:--------------------------------------------------------------------------:
:--------------------------------------------------------------------------:
(11)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	115	30.0	.45	PANEL
3	1007	430	500	3	46	19.9	.30	PANEL
5	607	454	500	5	253	69.7	1.05	PANEL
7	1007	454	250	7	253	115.7	1.73	PANEL

OPTICUT 110683 TEST #4

PLAN 698 4.0 % SAW 1 SHEETS 13 ◆ 5120 X 2070 X 15.0 137.8 M2 2.0

```
:--------------------------------------------------------------------------:
:775◆4  :      PANEL        :        :975◆2  PANEL               ::(40)
: X390  :        :          :        : X390       :              ::
:--------------------------------------------------------------------------:
:454◆11  :      :    :     :    :    :     :    :     :    ::(71)
: X1207  :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :   PANEL :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:    :   :      :    :     :    :    :     :    :     :    ::
:--------------------------------------------------------------------------:
:                      :          :          :              :
:1207          :907◆4  :          :          :          :XX:(260)
: X454PANEL    : X454  :        PANEL        :          :XX:
:              :       :          :          :          :XX:
:--------------------------------------------------------------------------:
:--------------------------------------------------------------------------:
(4)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	907	454	300	6	52	21.4	.32	PANEL
8	1207	454	150	8	156	85.5	1.28	PANEL
9	775	390	600	9	52	15.7	.24	PANEL
10	975	390	600	10	26	9.9	.15	PANEL

K

OPTICUT 110683 TEST #4

```
LAN 699 10.4 % SAW 1 SHEETS   8 * 5120 X 2070 X 15.0   84.8 M2   1.27

 :-----------------------------------------------------------------------:
 :430*11   :    :    :    :    :    :    :    :    :    :XXX: (335)
 : X607    :    :    :   PANEL:    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :-----------------------------------------------------------------------:
 :607*2 :         :907*4      :        :             :            :XX: (248)
 : X454PANEL      : X454      :      PANEL           :            :XX:
 :      :         :           :        :             :            :XX:
 :-----------------------------------------------------------------------:
 :    :    :     :    :     :    :    :     :    :     :    :
 :454*11   :     :    :     :    :    :     :    :     :    :: (71)
 : X907    :     :    :     :    :    :     :    :     :    ::
 :    :    :     :    :     :    :    :     :    :     :    ::
 :    :    :     :    :   PANEL :    :     :    :     :    ::
 :    :    :     :    :     :    :    :     :    :     :    ::
 :    :    :     :    :     :    :    :     :    :     :    ::
 :    :    :     :    :     :    :    :     :    :     :    ::
 :-----------------------------------------------------------------------:
 :                                                                       :
 :-----------------------------------------------------------------------:
(87)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	88	23.0	.34	PANEL
5	607	454	500	5	16	4.4	.07	PANEL
6	907	454	300	6	120	49.4	.74	PANEL
--	335	607	8	--	8	1.6	.02	OFFAL

OPTICUT 110683 TEST #4

```
PLAN 700  9.0 % SAW 1 SHEETS   9 * 5120 X 2070 X 15.0   95.4 M2   1.43

 :-----------------------------------------------------------------------:
 :975*5     :            : PANEL     :            :            :XX: (220)
 : X390     :            :           :            :            :XX:
 :-----------------------------------------------------------------------:
 :430*11   :    :    :    :    :    :    :    :    :    :XXX: (335)
 : X607    :    :    :    :    :    :    :    :    :    :XXX:
 :  *2:    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :-----------------------PANEL----------------------------:XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :    :    :    :    :    :    :    :    :    :    :    :XXX:
 :-----------------------------------------------------------------------:
 :      :                     :        :             :               :
 :607*2 :         :907*4      :        :             :            :XX: (248)
 : X430PANEL      : X430      :      PANEL           :            :XX:
 :      :         :           :        :             :            :XX:
 :-----------------------------------------------------------------------:
 :-----------------------------------------------------------------------:
(16)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	607	430	1000	1	216	56.4	.85	PANEL
2	907	430	600	2	36	14.0	.21	PANEL
10	975	[illegible]	[illegible]	10	45	17.1	.26	PANEL
--	335	607	[illegible]	--	[illegible]	3.7	.05	OFFAL

```
OPTICUT 110683  TEST #4      .

PLAN 701  4.4 % SAW 1 SHEETS   3 ◆ 5120 X 2070 X 15.0   31.8 M2    .4

  :------------------------------------------------------------:
  :390◆12 :   :    :    :PANEL    :    :   :    :    :   :XXXX: (380)
  : X357  :   :    :    :  :      :    :   :    :    :   :XXXX:
  :------------------------------------------------------------:
  :357◆6 :   :    :   :   :975◆3      :          :           : (8)
  : X390 :   :    :   :   : X390      :          :           :
  :--◆2----PANEL-----------:--◆2---------PANEL-----------------:
  :   :   :   :    :   :   :          :          :           :
  :   :   :   :    :   :   :          :          :           :
  :   :   :   :    :   :   :          :          :           :
  :------------------------------------------------------------:
  :    :    :    :    :     :    :    :     :    :     :     :
  :454◆11   :    :    :     :    :    :     :    :     :    :: (71)
  : X907    :    :    :     :    :    :     :    :     :    ::
  :    :    :    :    :     :    :    :     :    :     :    ::
  :    :    :    :    :   PANEL  :    :     :    :     :    ::
  :    :    :    :    :     :    :    :     :    :     :    ::
  :    :    :    :    :     :    :    :     :    :     :    ::
  :    :    :    :    :     :    :    :     :    :     :    ::
  :------------------------------------------------------------:
  :------------------------------------------------------------:
 (6)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	907	454	300	6	33	13.6	.20	PANEL
10	975	390	600	10	18	6.8	.10	PANEL
11	357	390	1200	11	72	10.0	.15	PANEL
--	380	357	3	--	3	.4	.01	OFFAL

OPTICUT 110683 TEST #4

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	607	430	1000	1	1005	5	262.3	3.93	PANEL
2	907	430	600	2	610	10	237.9	3.57	PANEL
3	1007	430	500	3	500	0	216.5	3.25	PANEL
4	1207	430	300	4	304	4	157.8	2.37	PANEL
5	607	454	500	5	515	15	141.9	2.13	PANEL
6	907	454	300	6	301	1	123.9	1.86	PANEL
7	1007	454	250	7	253	3	115.7	1.73	PANEL
8	1207	454	150	8	156	6	85.5	1.28	PANEL
9	775	390	600	9	604	4	182.6	2.74	PANEL
10	975	390	600	10	614	14	233.5	3.50	PANEL
11	357	390	1200	11	1206	6	167.9	2.52	PANEL
100	5120	2070	9999	12	191	-9808	2024.3	30.36	PANEL

```
LINE/PLAN DEPENDENCE
  1: 1 2 . 4 . . 7 . 910 .
  2: . 2 3 4 5 . . . .10 .
  3: 1 2 . . . . 7 . . . .
  4: . . 3 . 5 6 . . . . .
  5: . . . 4 . 6 7 . 9 . .
  6: . . . . . 6 . 8 9 .11
  7: . . . . . . 7 . . . .
  8: . . . . . . . 8 . . .
  9: 1 . 3 4 . 6 . 8 . . .
 10: 1 2 3 4 5 6 . 8 .1011
 11: . 2 . . . . . . . .11
100: 1 2 3 4 5 6 7 8 91011
WHAT NEXT? 1
```

M

Test No. 4.

number of panel orders 9.

Pattern Systems (c) POPS Monday 18th Apr 1

PANEL REQUIREMENTS

NO.	PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
81.	PANEL 9.1.	2165	577	15	N	Y	50	10
82.	PANEL 9.2.	2165	424	15	N	Y	100	10
83.	PANEL 9.3.	424	557	15	N	Y	100	10
84.	PANEL 9.4.	2165	407	15	N	Y	100	10
85.	PANEL 9.5.	688	553	15	N	Y	300	10
86.	PANEL 9.6.	553	553	15	N	Y	400	10
87.	PANEL 9.7.	688	403	15	N	Y	600	10
88.	PANEL 9.8.	424	407	15	N	Y	100	10
89.	PANEL 9.9.	553	403	15	N	Y	610	10

Pattern Systems (c) POPS Monday 18th Apr 1

BOARD AVAILABILITY

NO.	BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
2.	BOARD 2.	2070	2560	15	30000

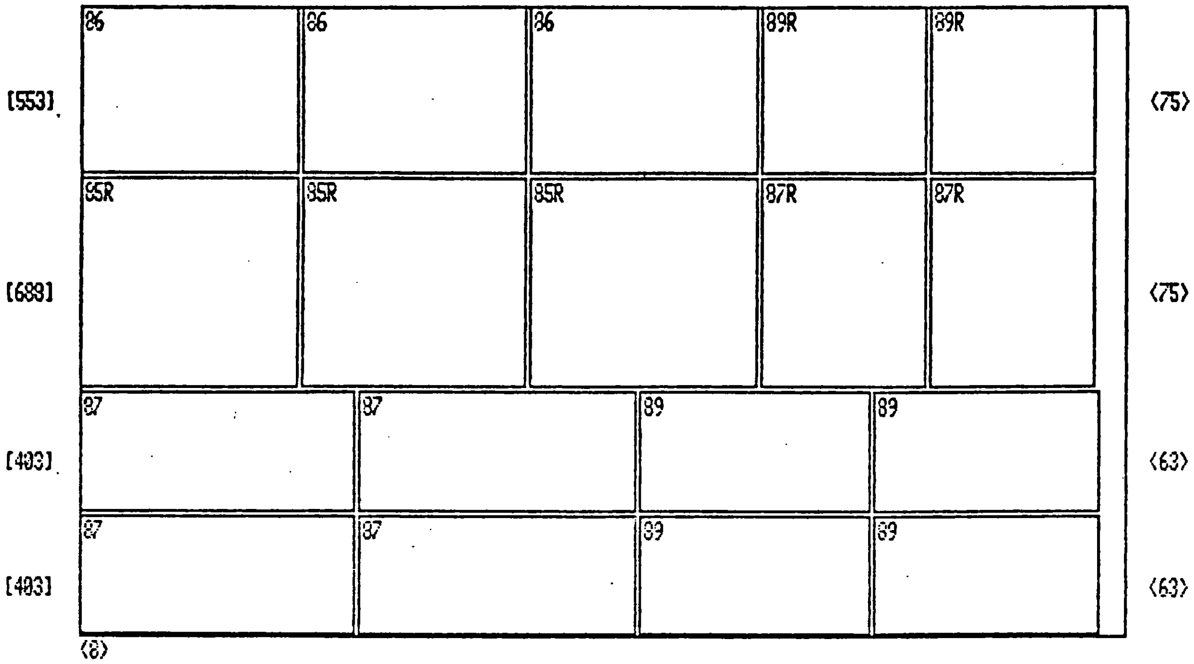
A

 POPS Monday 18th Apr 1983

CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m²)	% Panels	% Boards
Panel requirements :	821.88	100.10	87.71
Extras produced :	14.20	1.7[illegible]	1.51
Board area used :	937.95	114.24	100.10
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	11.39	1.38	1.21
Edge trim :	0.00	0.00	0.00
Additional waste :	90.48	11.02	9.65
WASTAGE :	101.87	12.40	10.87

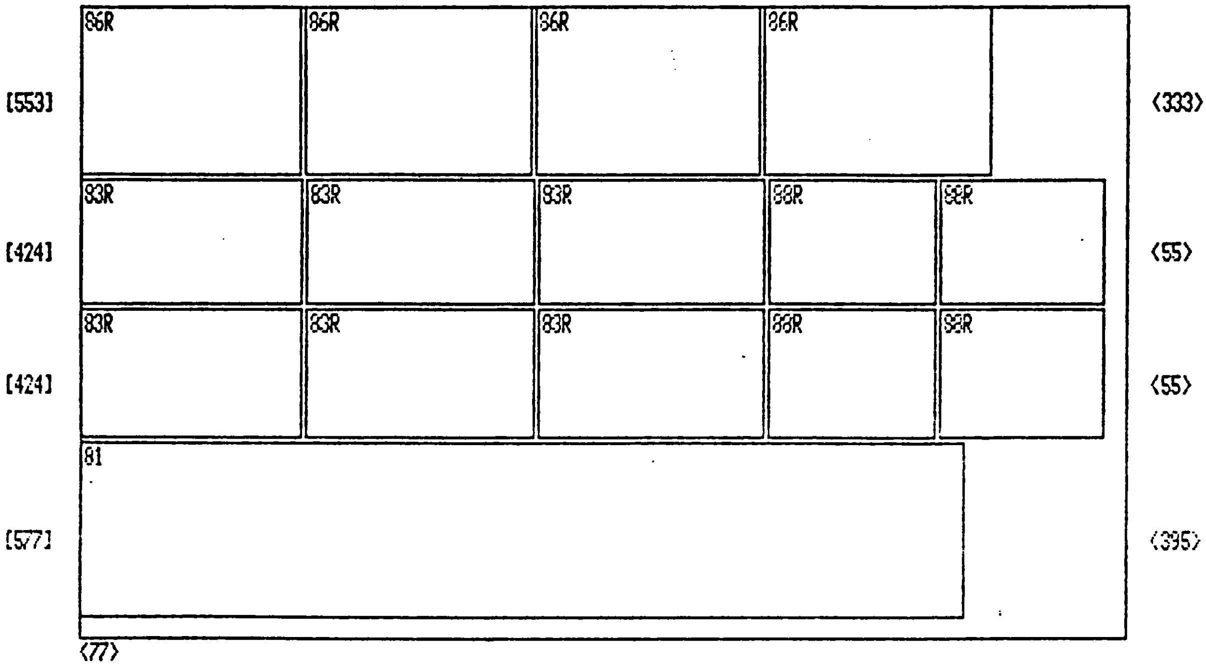
PATTERN NO. : 1.1. GOAL DIRECTION : W (907)
BOARD SIZE : 2560 x 2070. NO. REQUIRED : 102. WASTE : 4.52 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
86.	PANEL 9.6.	553	553	400	306	94
89.	PANEL 9.9.	553	403	610	612	- 2
87.	PANEL 9.7.	688	403	600	612	- 12
85.	PANEL 9.5.	688	553	300	306	- 6

C

PATTERN NO. : 2.1. GOAL DIRECTION : W (723)
BOARD SIZE : 2560 x 2070. NO. REQUIRED : 17. WASTE : 13.57 %

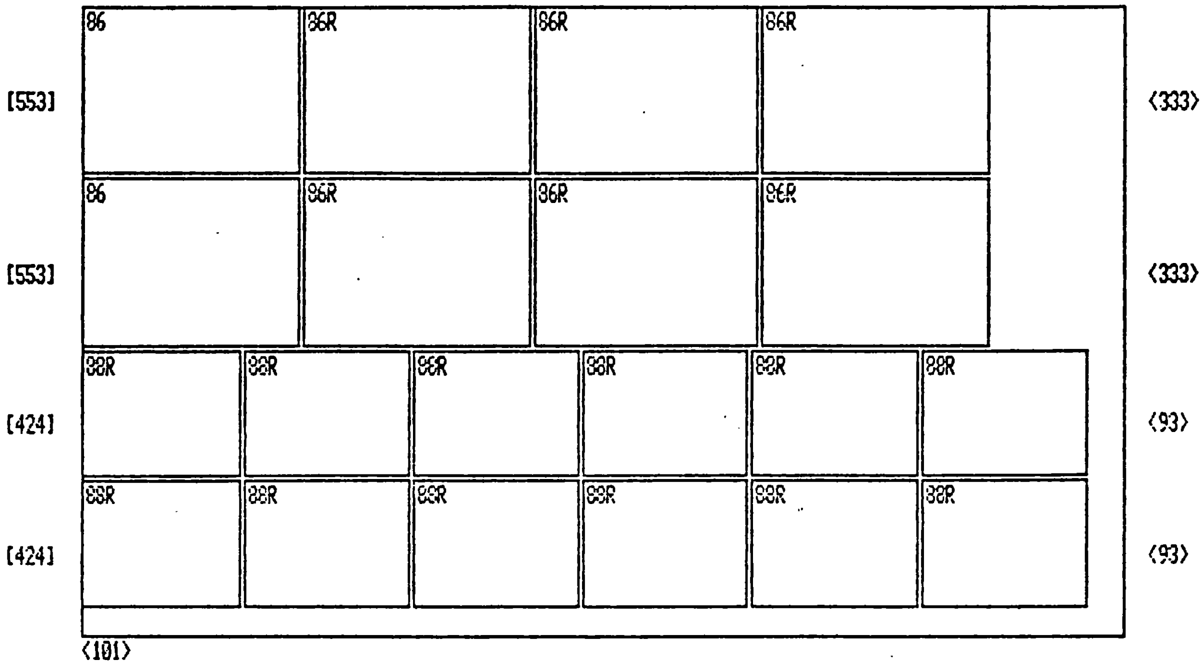


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
86.	PANEL 9.6.	553	553	400	68	26
83.	PANEL 9.3.	424	557	100	102	- 2
88.	PANEL 9.8.	424	407	100	68	32
81.	PANEL 9.1.	2165	577	50	17	33

D

PATTERN NO. : 3.1. GOAL DIRECTION : W (697)

BOARD SIZE : 2560 x 2070. NO. REQUIRED : 4. WASTE : 14.75 %

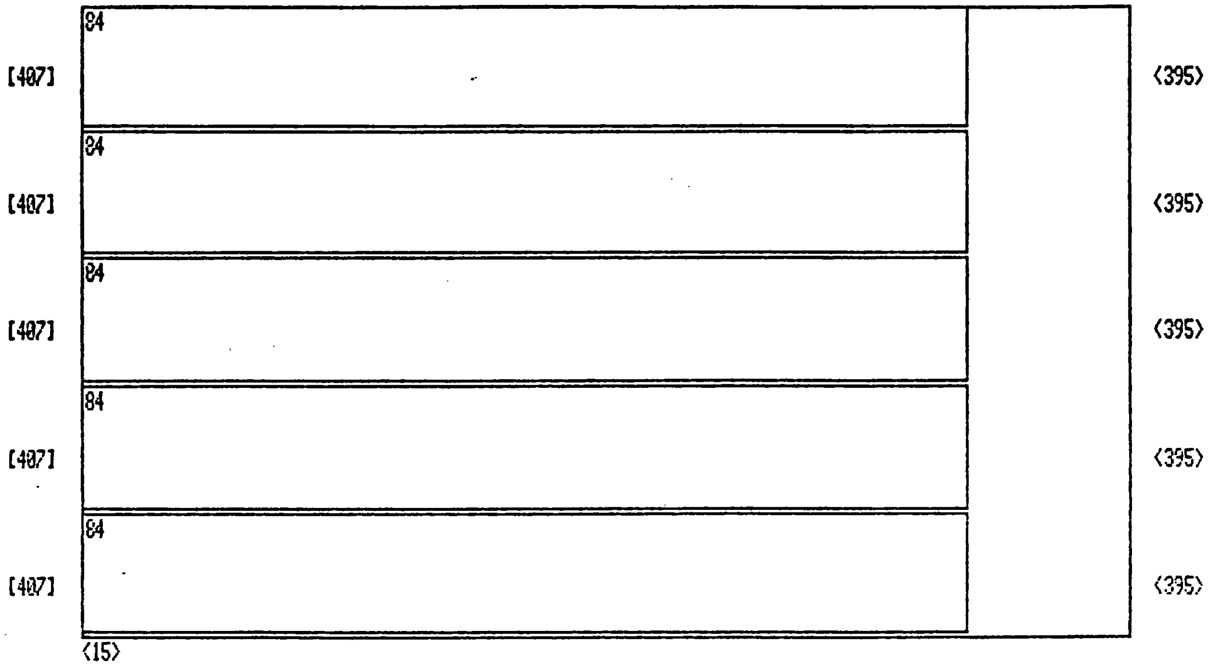


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
86.	PANEL 9.6.	553	553	400	32	- 6
88.	PANEL 9.8.	424	407	100	48	- 16

E

PATTERN NO. : 4.1. GOAL DIRECTION : W (628)

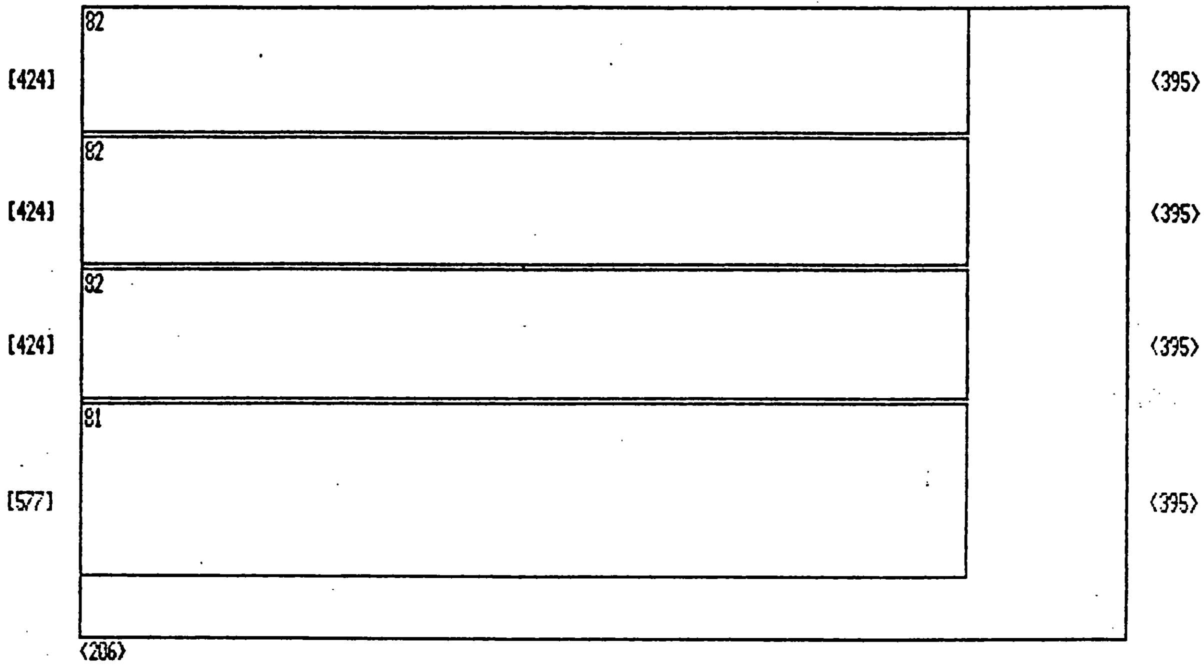
BOARD SIZE : 2560 x 2070. NO. REQUIRED : 20. WASTE : 16.85 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RO.
84.	PANEL 9.4.	2165	407	100	100	0

F

PATTERN NO. : 5.1. GOAL DIRECTION : W (492)
BOARD SIZE : 2560 x 2070. NO. REQUIRED : 34. WASTE : 24.45 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
82.	PANEL 9.2.	2165	424	100	102	- 2
81.	PANEL 9.1.	2165	577	50	34	- 1

```
SUMMARY        M2      M3     %/P      %/B
PANELS      822.0   12.33   100.0     87.6
EXTRA         6.0     .09      .7       .6
SHEETS      938.0   14.07   114.1    100.0
WASTE       110.0    1.65    13.4     11.7
OFFAL        56.8     .85     6.9      6.1

SHEET USAGE
 177 ♦ 2070 X 2560
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 1
OPTICUT 110683  TEST

 L/N LENGTH WIDTH  REQ IDENT   CUT DIFF.       M2       M3 DESCRIPTION
   1  2165   577    50     1    50     0     62.5      .94
   2  2165   424   100     2   102     2     93.6     1.40
   3   424   557   100     3   104     4     24.6      .37
   4  2165   407   100     4   100     0     88.1     1.32
   5   688   553   300     5   301     1    114.5     1.72
   6   553   553   400     6   404     4    123.5     1.85
   7   688   403   600     7   600     0    166.4     2.50
   8   424   407   100     8   104     4     17.9      .27
   9   553   403   610     9   614     4    136.8     2.05
 100  2070  2560 10000     1   177 -9823    938.0    14.07
LINE/PLAN DEPENDENCE
  1: 1 . . . . . . .
  2: 1 2 . . . . . .
  3: . . . . 6 . 8 .
  4: . . 4 . . . . .
  5: . . . 5 6 7 8 .
  6: . . . 5 6 7 8 9
  7: . . . 5 . 7 . 9
  8: . . . . 6 . 8 .
  9: . . . 5 . 7 8 9
100: 1 2 4 5 6 7 8 9
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 4
```

H

PLAN 751 22.3 % SAW 1 SHEETS 25 ◆ 2070 X 2560 X 15.0 132.5 M2 1.99

```
:-------------------------------------------------------------:
:424◆2      :             :577◆2     :                 :: (48)
: X2165     :             : X2165    :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:           :             :          :                 ::
:-------------------------------------------------------------:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:-------------------------------------------------------------:
(390)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	2165	577	50	1	50	62.5	.94	
2	2165	424	100	2	50	45.9	.69	
--	2070	390	25	--	25	20.2	.30	OFFAL

OPTICUT 110683 TEST

PLAN 752 44.3 % SAW 1 SHEETS 13 ◆ 2070 X 2560 X 15.0 68.9 M2 1.03

```
:-------------------------------------------------------------:
:424◆4      :             :           :             :XXXXXXXXX: (354)
: X2165     :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:           :             :           :             :XXXXXXXXX:
:-------------------------------------------------------------:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:-------------------------------------------------------------:
(390)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	2165	424	100	2	52	47.7	.72	
--	2070	390	13	--	13	10.5	.16	OFFAL
--	354	2165	13	--	13	10.0	.15	OFFAL

I

```
PLAN 754 20.3 % SAW 1 SHEETS  20 ◆ 2070 X 2560 X 15.0  106.0 M2   1.59

:--------------------------------------------------------------:
:407◆5      :            :            :           :            :(10)
: X2165     :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:           :            :            :           :            :
:--------------------------------------------------------------:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:--------------------------------------------------------------:
(390)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
4	2165	407	100	4	100	88.1	1.32	
--	2070	390	20	--	20	16.1	.24	OFFAL

OPTICUT 110683 TEST

```
PLAN 755  8.3 % SAW 1 SHEETS  20 ◆ 2070 X 2560 X 15.0  106.0 M2   1.59

:--------------------------------------------------------------:
:403◆2      :            :553◆2           :                :XXX:(138)
: X688      :            : X688           :                :XXX:
:  ◆2       :            :  ◆2            :                :XXX:
:           :            :                :                :XXX:
:------------------------:---------------------------------:XXX:
:           :            :                :                :XXX:
:           :            :                :                :XXX:
:           :            :                :                :XXX:
:           :            :                :                :XXX:
:--------------------------------------------------------------:
:403◆2      :            :688                 :553             :(3)
: X553      :            : X553               : X553           :
:  ◆2       :            :  ◆2                :  ◆2            :
:------------------------:--------------------:----------------:
:           :            :                    :                :
:           :            :                    :                :
:           :            :                    :                :
:--------------------------------------------------------------:
:                                                              :
:--------------------------------------------------------------:
(58)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	688	553	300	5	120	45.7	.68	
6	553	553	400	6	40	12.2	.18	
7	688	403	600	7	80	22.2	.33	
9	553	403	610	9	80	17.8	.27	

```
PLAN 756  9.6 % SAW 1 SHEETS   9 ◆ 2070 X 2560 X 15.0   47.7 M2    .72

   :------------------------------------------------------------:
   :407◆2      :           :557◆2           :                :XX: (122)
   : X424      :           : X424           :                :XX:
   :--◆2-------------------:--◆2-----------------------------:XX:
   :           :           :                :                :XX:
   :           :           :                :                :XX:
   :------------------------------------------------------------:
   :688◆2              :                    :553             :XX: (126)
   : X553              :                    : X553           :XX:
   :  ◆3               :                    :  ◆3            :XX:
   :----------------------------------------:----------------:XX:
   :                   :                    :                :XX:
   :                   :                    :                :XX:
   :                   :                    :                :XX:
   :----------------------------------------:----------------:XX:
   :                   :                    :                :XX:
   :                   :                    :                :XX:
   :                   :                    :                :XX:
   :                   :                    :                :XX:
   :------------------------------------------------------------:
   :------------------------------------------------------------:
  (28)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
3	424	557	100	3	36	8.5	.13	
5	688	553	300	5	54	20.5	.31	
6	553	553	400	6	27	8.3	.12	
8	424	407	100	8	36	6.2	.09	

OPTICUT 110683 TEST

```
PLAN 757  5.2 % SAW 1 SHEETS  38 ◆ 2070 X 2560 X 15.0  201.4 M2   3.02

   :------------------------------------------------------------:
   :403◆5      :           :           :           :            : (30)
   : X688      :           :           :           :            :
   :  ◆2       :           :           :           :            :
   :           :           :           :           :            :
   :------------------------------------------------------------:
   :           :           :           :           :            :
   :           :           :           :           :            :
   :           :           :           :           :            :
   :           :           :           :           :            :
   :------------------------------------------------------------:
   :403◆2      :           :553            :688                 : (3)
   : X553      :           : X553          : X553               :
   :  ◆2       :           :  ◆2           :  ◆2                :
   :-----------------------:---------------:--------------------:
   :           :           :               :                    :
   :           :           :               :                    :
   :           :           :               :                    :
   :------------------------------------------------------------:
   :                                                            :
   :------------------------------------------------------------:
  (58)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	688	553	300	5	76	28.9	.43	
6	553	553	400	6	76	23.2	.35	
7	688	403	600	7	380	105.4	1.58	
9	553	403	610	9	152	33.9	.51	

K

```
PLAN 758  5.3 % SAW 1 SHEETS  17 ◆ 2070 X 2560 X 15.0   90.1 M2   1.35

  :----------------------------------------------------------------:
  :407◆2      :           :557◆2     :                  :XX: (122)
  : X424      :           : X424     :                  :XX:
  :--◆2-------------------:--◆2-----------------------------:XX:
  :           :           :          :                  :XX:
  :           :           :          :                  :XX:
  :----------------------------------------------------------------:
  :403◆2      :           :688                 :553              : (3)
  : X553      :           : X553               : X553            :
  :  ◆3       :           :  ◆3                :  ◆3             :
  :-----------------------:--------------------:-----------------:
  :           :           :                    :                 :
  :           :           :                    :                 :
  :           :           :                    :                 :
  :-----------------------:--------------------:-----------------:
  :           :           :                    :                 :
  :           :           :                    :                 :
  :           :           :                    :                 :
  :           :           :                    :                 :
  :----------------------------------------------------------------:
  :----------------------------------------------------------------:
 (28)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
3	424	557	100	3	68	16.1	.24	
5	688	553	300	5	51	19.4	.29	
6	553	553	400	6	51	15.6	.23	
8	424	407	100	8	68	11.7	.18	
9	553	403	610	9	102	22.7	.34	

OPTICUT 110683 TEST

```
PLAN 759 12.1 % SAW 1 SHEETS  35 ◆ 2070 X 2560 X 15.0  185.5 M2   2.78

  :----------------------------------------------------------------:
  :688◆2                :                  :553             :XX: (126)
  : X403                :                  : X403           :XX:
  :--◆2-------------------------------------:--◆2------------:XX:
  :                     :                  :                :XX:
  :                     :                  :                :XX:
  :----------------------------------------------------------------:
  :403◆2      :           :553◆2           :              :XXX: (138)
  : X553      :           : X553           :              :XXX:
  :  ◆3       :           :  ◆3            :              :XXX:
  :-----------------------:-------------------------------:XXX:
  :           :           :                :              :XXX:
  :           :           :                :              :XXX:
  :           :           :                :              :XXX:
  :-----------------------:-------------------------------:XXX:
  :           :           :                :              :XXX:
  :           :           :                :              :XXX:
  :           :           :                :              :XXX:
  :           :           :                :              :XXX:
  :----------------------------------------------------------------:
  :----------------------------------------------------------------:
 (70)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	553	553	400	6	210	64.2	.96	
7	688	403	600	7	140	38.8	.58	
9	553	403	610	9	280	62.4	.94	

Test No. 5.

number of panel orders 7.

Pattern Systems (c) POPS Monday 18th Apr 1983

PANEL REQUIREMENTS

NO.	PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
57.	PANEL 6.1.	939	419	15	N	Y	100	10
58.	PANEL 6.2.	581	246	15	N	Y	330	10
59.	PANEL 6.3.	581	396	15	N	Y	3000	10
60.	PANEL 6.4.	444	556	15	N	Y	600	10
61.	PANEL 6.5.	431	396	15	N	Y	200	10
[illegible]	PANEL 6.6.	444	396	15	N	Y	420	10
63.	PANEL 6.7.	2039	419	15	N	Y	100	10

Pattern Systems (c) POPS Monday 18th Apr 1983

BOARD AVAILABILITY

NO.	BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
1.	BOARD 1.	5120	2070	15	30000

A

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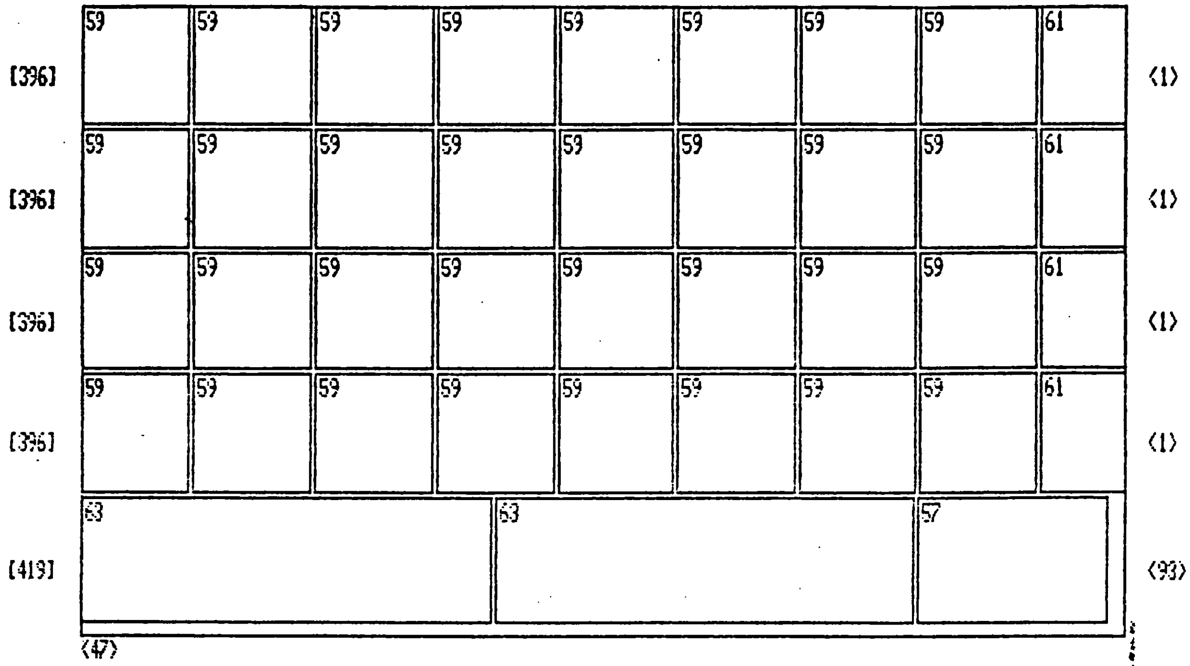
CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m²)	% Panels	% Boards
Panel requirements :	1117.96	100.00	93.39
Extras produced :	12.17	1.08	1.01
Board area used :	1197.61	107.21	100.05
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	20.16	1.80	1.68
Edge trim :	0.00	0.00	0.00
Additional waste :	47.32	4.23	3.95
WASTAGE :	67.48	6.04	5.63

B

PATTERN NO. : 1.1. GOAL DIRECTION : P (1161)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 50. WASTE : 4.25 %

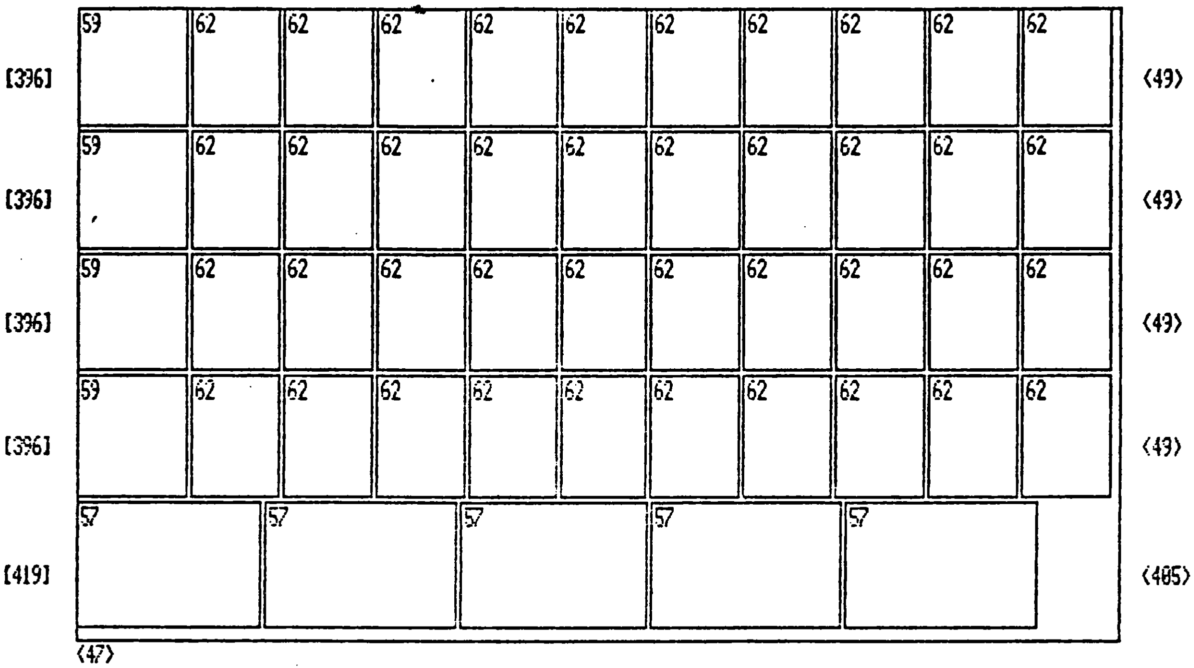


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	1600	1400
61.	PANEL 6.5.	431	396	200	200	0
63.	PANEL 6.7.	2039	419	100	100	0
57.	PANEL 6.1.	939	419	100	50	50

c

PATTERN NO. : 2.1. GOAL DIRECTION : P (1223)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 11. WASTE : 6.39 %

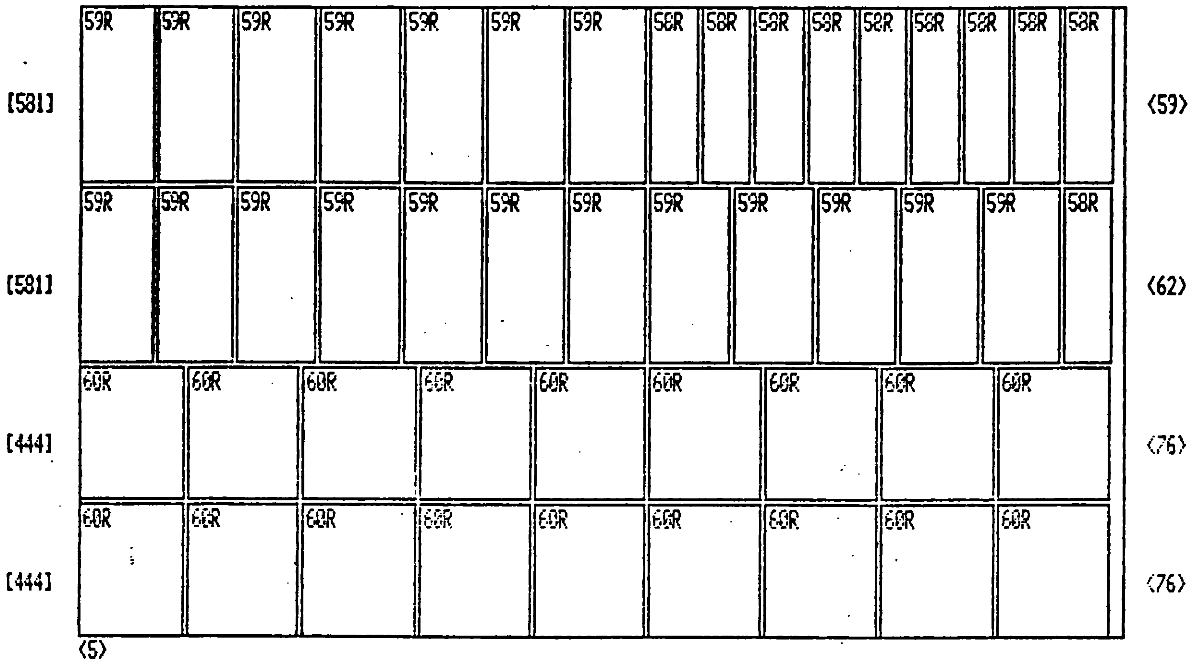


No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	44	1356
62.	PANEL 6.6.	444	396	420	440	- 20
57.	PANEL 6.1.	939	419	100	55	- 5

D

PATTERN NO. : 3.1. GOAL DIRECTION : P (1214)

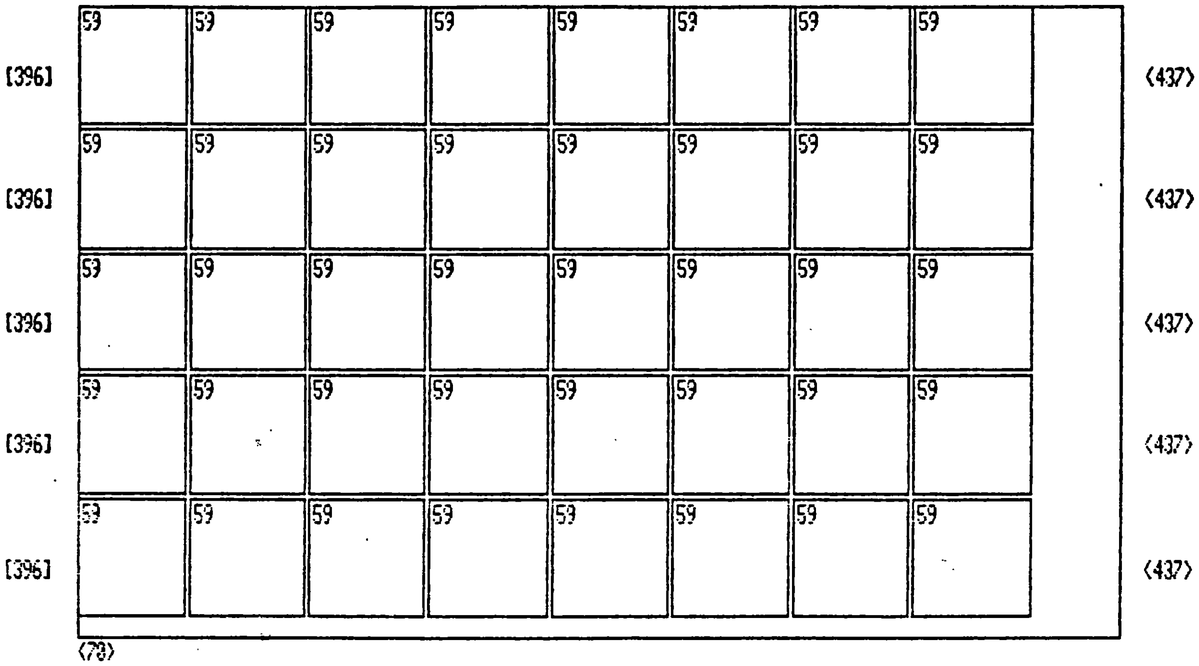
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 34. WASTE : 3.34 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	646	710
58.	PANEL 6.2.	581	246	330	340	- 10
60.	PANEL 6.4.	444	556	600	612	- 12

E

PATTERN NO. : 4.1. GOAL DIRECTION : P (1338)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 18. WASTE : 13.16 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RO.
59.	PANEL 6.3.	581	396	3000	720	- 10

F

```
SUMMARY       M2       M3      %/P      %/B
PANELS     1118.3    16.77    100.0     94.2
EXTRA         7.9      .12       .7       .7
SHEETS     1187.0    17.81    106.1    100.0
WASTE        60.9      .91      5.4      5.1


OFFAL         3.5      .05       .3       .3

SHEET USAGE
 112 ♦ 5120 X 2070
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 1
```

```
OPTICUT 110683  TEST # 2.

 L/N LENGTH WIDTH  REQ IDENT   CUT DIFF.      M2      M3 DESCRIPTION
   1    939   419  100     1   100     0    39.3     .59 PANEL
   2    581   246  330     2   333     3    47.6     .71 PANEL
   3    581   396 3000     3  3019    19   694.6   10.42 PANEL
   4    444   556  600     4   611    11   150.8    2.26 PANEL
   5    431   396  200     5   200     0    34.1     .51 PANEL
   6    444   396  420     6   422     2    74.2    1.11 PANEL
   7   2039   419  100     7   100     0    85.4    1.28 PANEL
 100   5120  2070 9999    12   112 -9887  1187.0   17.81 PANEL
LINE/PLAN DEPENDENCE
   1: 1 . . . . . 7
   2: . 2 . . 5 6 7
   3: 1 2 3 4 5 6 7
   4: . . . 4 5 6 .
   5: . . 3 4 . . .
   6: 1 . . . 5 . .
   7: . . . . . . 7
 100: 1 2 3 4 5 6 7
```

PLAN 731 7.9 % SAW 1 SHEETS 5 ◆ 5120 X 2070 X 15.0 53.0 M2 .79

```
:------------------------------------------------------------:
:939◆5     :          :          :          :         :XXXX: (400)
: X419     :          :          :          :         :XXXX:
:  ◆2      :          :          :          :         :XXXX:
:----------------------PANEL----------------------------:XXXX:
:          :          :          :          :         :XXXX:
:          :          :          :          :         :XXXX:
:          :          :          :          :         :XXXX:
:------------------------------------------------------------:
:444◆2    :581◆7 :      :      :      :      :      :     :X: (120)
: X396    : X396 :      :      :      :      :      :     :X:
:--◆3-----:--◆3-----------------------------------------:X:
:    :    :      :      :      :      :      :      :     :X:
: PANEL   :      :      :     PANEL   :      :      :     :X:
:    :    :      :      :      :      :      :      :     :X:
:---------:---------------------------------------------:X:
:    :    :      :      :      :      :      :      :     :X:
:    :    :      :      :      :      :      :      :     :X:
:    :    :      :      :      :      :      :      :     :X:
:------------------------------------------------------------:
:------------------------------------------------------------:
(19)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	939	419	100	1	50	19.7	.30	PANEL
3	581	396	3000	3	105	24.2	.36	PANEL
6	444	396	420	6	30	5.3	.08	PANEL
--	400	419	10	--	10	1.7	.03	OFFAL

OPTICUT 110683 TEST # 2.

PLAN 732 7.5 % SAW 1 SHEETS 17 ◆ 5120 X 2070 X 15.0 180.2 M2 2.70

```
:------------------------------------------------------------:
:581◆8:      :      :    PANEL     :      :      :         :XXXX: (432)
:-X246-------------------------------------------------------:
:246  :396◆12   :   :    :    :    :    :    :    :    :    :: (57)
: X581 :X581:   :   :    :    :    :    :    :    :    :    ::
: :◆3  :  ◆3 :  :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
:-:---------------------------------------------------------::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
PANE   :    :   :   :    :PANEL    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
:-:---------------------------------------------------------::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
: :    :    :   :   :    :    :    :    :    :    :    :    ::
:------------------------------------------------------------:
:------------------------------------------------------------:
(61)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	581	246	330	2	187	26.7	.40	PANEL
3	581	396	3000	3	612	140.8	2.11	PANEL
--	432	246	17	--	17	1.8	.03	OFFAL

H

PLAN 733 8.6 % SAW 1 SHEETS 14 ◆ 5120 X 2070 X 15.0 148.4 M2 2.25

```
:----------------------------------------------------------------------:
:431◆2     :581◆7 :       :       :       :       :       :       :X: (146)
: X396     : X396 :       :       :       :       :       :       :X:
:--◆5------:--◆5--------------------------------------------------:X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:----------:------------------------------------------------------:X:
:    :     :      :       :       :       :       :       :       :X:
: PANEL    :      :       :       :PANEL  :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:----------:------------------------------------------------------:X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:----------:------------------------------------------------------:X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:    :     :      :       :       :       :       :       :       :X:
:----------------------------------------------------------------------:
:----------------------------------------------------------------------:
(65)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
3	581	396	3000	3	490	112.7	1.69	PANEL
5	431	396	200	5	140	23.9	.36	PANEL

OPTICUT 110683 TEST # 2.

PLAN 734 3.5 % SAW 1 SHEETS 3 ◆ 5120 X 2070 X 15.0 31.8 M2 .48

```
:----------------------------------------------------------------------:
:556◆9:     :      :       :       :       :       :       :       :: (71)
: X444:     :      :     PANEL     :       :       :       :       ::
:     :     :      :       :       :       :       :       :       ::
:----------------------------------------------------------------------:
:431◆5    :    :     :     :581◆5 :       :       :       :        : (10)
: X396    :    :     :     : X396 :       :       :       :        :
:--◆4-----------------------:--◆4-----------------------------------:
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:--------PANEL--------------:---------------PANEL-------------------:
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:---------------------------:---------------------------------------:
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:    :    :    :     :     :       :       :       :       :        :
:----------------------------------------------------------------------:
:----------------------------------------------------------------------:
(17)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
3	581	396	3000	3	60	13.8	.21	PANEL
4	444	556	600	4	27	6.7	.10	PANEL
5	431	396	200	5	60	10.2	.15	PANEL

I

OPTICUT 110683 TEST # 2.

PLAN 735 3.5 % SAW 1 SHEETS 28 ◆ 5120 X 2070 X 15.0 296.8 M2 4.45

```
:------------------------------------------------------------------:
:556◆4:      :     :      :396◆7   :    :    :    :    :    :: (69)
: X444:      :     :      : X444   :    :    :    :    :    ::
:  ◆2 :      :     :      :  ◆2:   :    :    :    :    :    ::
:---------PANEL-----------:-------------PANEL----------------::
:     :      :     :      :    :   :    :    :    :    :    ::
:     :      :     :      :    :   :    :    :    :    :    ::
:     :      :     :      :    :   :    :    :    :    :    ::
:------------------------------------------------------------------:
:246   :396◆12  :   :     :    :   :    :    :    :    :    :: (57)
: X581 :X581:   :   :     :    :   :    :    :    :    :    ::
: :◆2  : ◆2 :   :   :     :    :   :    :    :    :    :    ::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
PANE-------------------------PANEL---------------------------::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
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:------------------------------------------------------------------:
:------------------------------------------------------------------:
(0)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	581	246	330	2	56	8.0	.12	PANEL
3	581	396	3000	3	672	154.6	2.32	PANEL
4	444	556	600	4	224	55.3	.83	PANEL
6	444	396	420	6	392	68.9	1.03	PANEL

OPTICUT 110683 TEST # 2.

PLAN 736 3.4 % SAW 1 SHEETS 20 ◆ 5120 X 2070 X 15.0 212.0 M2 3.18

```
:------------------------------------------------------------------:
:556◆9:      :     :      :      :     :      :     :        :: (71)
: X444:      :     :      :      :     :      :     :        ::
:  ◆2 :      :     :      :      :     :      :     :        ::
:-------------------------PANEL------------------------------::
:     :      :     :      :      :     :      :     :        ::
:     :      :     :      :      :     :      :     :        ::
:     :      :     :      :      :     :      :     :        ::
:------------------------------------------------------------------:
:246   :396◆12  :   :     :    :   :    :    :    :    :    :: (57)
: X581 :X581:   :   :     :    :   :    :    :    :    :    ::
: :◆2  : ◆2 :   :   :     :    :   :    :    :    :    :    ::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
PANE-------------------------PANEL---------------------------::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
: :    :    :   :   :     :    :   :    :    :    :    :    ::
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: :    :    :   :   :     :    :   :    :    :    :    :    ::
:------------------------------------------------------------------:
:------------------------------------------------------------------:
(0)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
2	581	246	330	2	40	5.7	.09	PANEL
3	581	396	3000	3	480	110.4	1.66	PANEL
4	444	556	600	4	360	88.9	1.33	PANEL

PLAN 737 5.9 % SAW 1 SHEETS 25 ◆ 5120 X 2070 X 15.0 265.0 M2   3.57

```
:-----------------------------------------------------------:
:2039◆2                 :                       :939       :: (88)
: X419                  :                       : X419     ::
:  ◆2                   :                       :  ◆2      ::
:-------------------PANEL-----------------------:-PANEL----::
:                       :                       :          ::
:                       :                       :          ::
:                       :                       :          ::
:-----------------------------------------------------------:
:246  :396◆12    :   :    :    :   :    :    :    :   :    :: (57)
: X581 :X581:    :   :    :    :   :    :    :    :   :    ::
: :◆2  : ◆2 :    :   :    :    :   :    :    :    :   :    ::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
PANE----------------------PANEL----------------------------::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
: :    :    :    :   :    :    :   :    :    :    :   :    ::
:-----------------------------------------------------------:
:-----------------------------------------------------------:
(50)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	939	419	100	1	50	19.7	.30	PANEL
2	581	246	330	2	50	7.1	.11	PANEL
3	581	396	3000	3	600	138.0	2.07	PANEL
7	2039	419	100	7	100	85.4	1.28	PANEL

OPTICUT 110683 TEST # 2.

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	939	419	100	1	100	0	39.3	.59	PANEL
2	581	246	330	2	333	3	47.6	.71	PANEL
3	581	396	3000	3	3019	19	694.6	10.42	PANEL
4	444	556	600	4	611	11	150.8	2.26	PANEL
5	431	396	200	5	200	0	34.1	.51	PANEL
6	444	396	420	6	422	2	74.2	1.11	PANEL
7	2039	419	100	7	100	0	85.4	1.28	PANEL
100	5120	2070	9999	12	112	-9887	1187.0	17.81	PANEL

```
LINE/PLAN DEPENDENCE
  1: 1 . . . . . 7
  2: . 2 . . 5 6 7
  3: 1 2 3 4 5 6 7
  4: . . . 4 5 6 .
  5: . . 3 4 . . .
  6: 1 . . . 5 . .
  7: . . . . . . 7
100: 1 2 3 4 5 6 7
WHAT NEXT?
```

K

Test No. 6.

number of panel orders 10.

Pattern Systems (c) POPS Monday 18th Apr 1983

PANEL REQUIREMENTS

NO.	PANEL CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	MULTIPLE (Y/N)	ROTATABLE (Y/N)	QUANTITY	EXTRAS
11.	PANEL 2.1.	1887	292	15	N	Y	300	10
12.	PANEL 2.2.	1887	292	15	N	Y	30	10
13.	PANEL 2.3.	1887	282	15	N	Y	30	10
14.	PANEL 2.4.	832	292	15	N	Y	260	10
15.	PANEL 2.5.	541	292	15	N	Y	160	10
16.	PANEL 2.6.	711	292	15	N	Y	410	10
17.	PANEL 2.7.	437	292	15	N	Y	200	10
18.	PANEL 2.8.	675	276	15	N	Y	280	10
19.	PANEL 2.9.	325	276	15	N	Y	820	10
20.	PANEL 2.10.	475	276	15	N	Y	200	10

Pattern Systems (c) POPS Monday 18th Apr 1983

BOARD AVAILABILITY

NO.	BOARD CODE	LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	QUANTITY
1.	BOARD 1.	5120	2070	15	30000

A

©Pattern Systems	POPS	Monday	18th Apr 1983

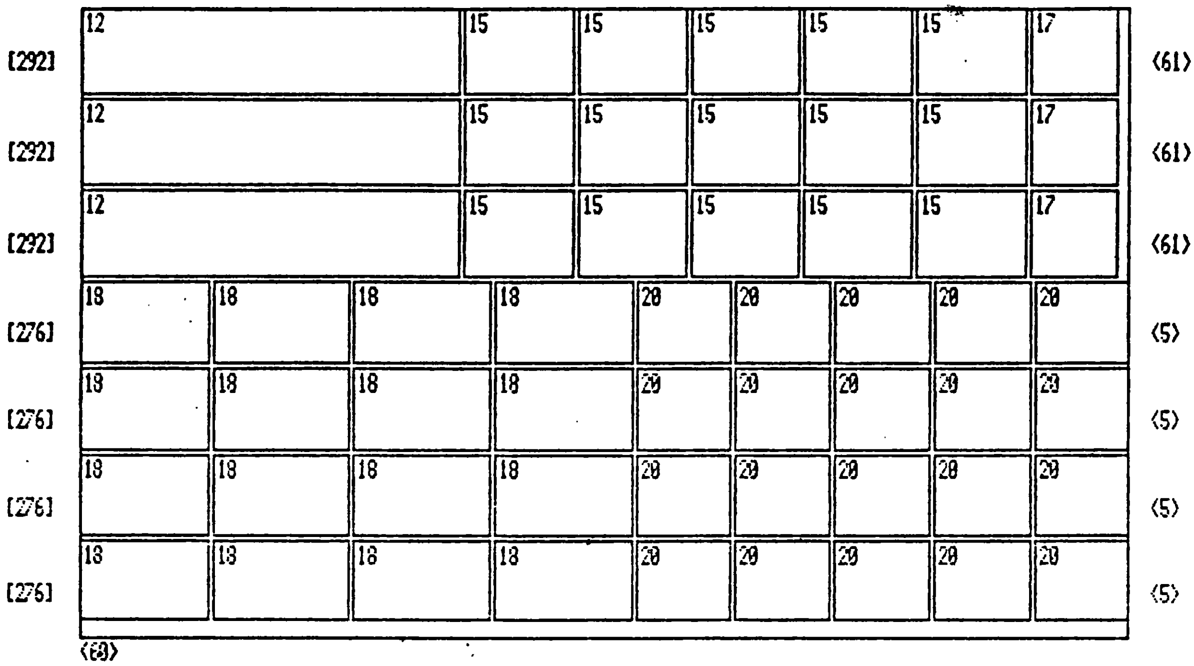
CURRENT OPTIMISATION SUMMARY

SUMMARY	Area (m^2)	% Panels	% Boards
Panel requirements :	548.78	100.14	87.80
Extras produced :	30.17	5.50	4.82
Board area used :	625.30	114.10	100.04
Usable off-cuts :	0.00	0.00	0.00
Process waste :			
Saw kerf :	12.55	2.29	2.00
Edge trim :	0.00	0.00	0.00
Additional waste :	33.80	6.16	5.40
WASTAGE :	46.35	8.45	7.41

B

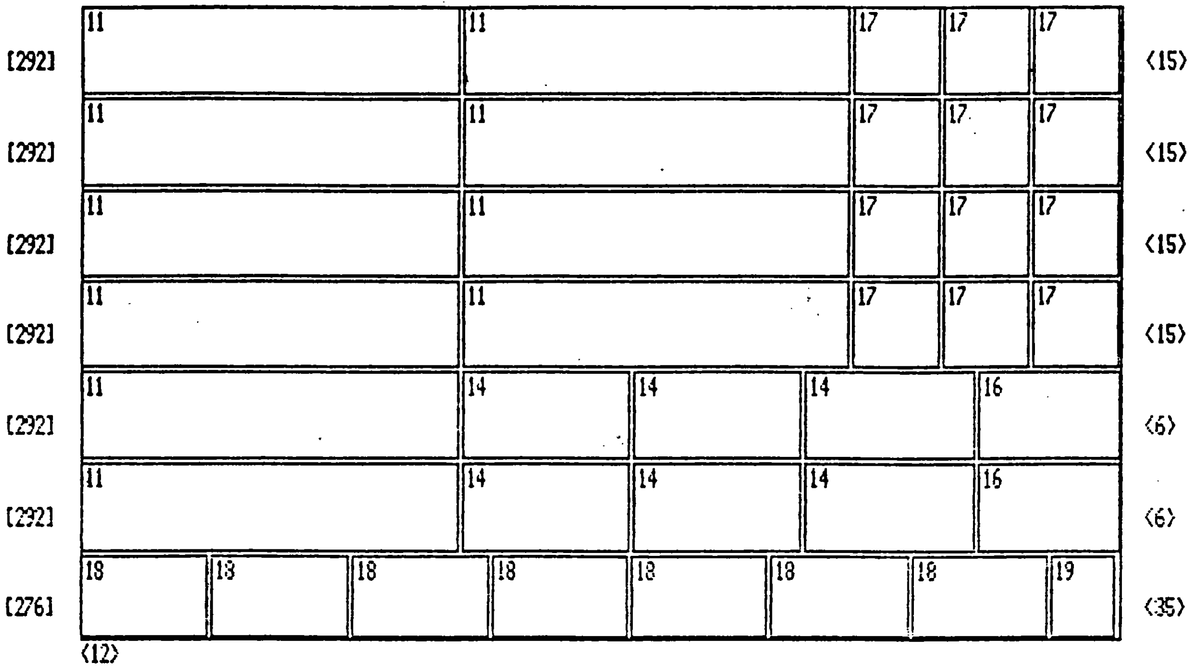
PATTERN NO. : 1.1. GOAL DIRECTION : P (1277)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 11. WASTE : 5.56 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
12.	PANEL 2.2.	1887	292	30	33	- 3
15.	PANEL 2.5.	541	292	160	165	- 5
17.	PANEL 2.7.	437	292	200	33	167
18.	PANEL 2.8.	675	276	280	176	104
20.	PANEL 2.10.	475	276	200	220	- 20

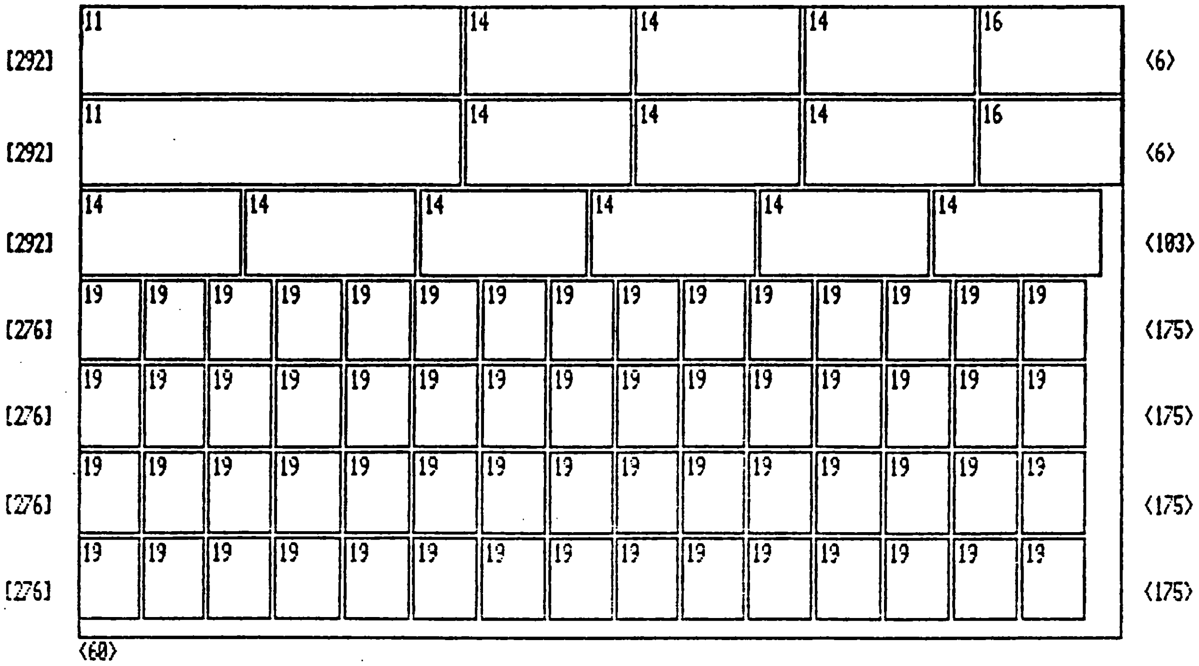
PATTERN NO. : 2.1. GOAL DIRECTION : P (1385)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 15. WASTE : 2.74 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
11.	PANEL 2.1.	1887	292	300	150	150
17.	PANEL 2.7.	437	292	200	180	- 13
14.	PANEL 2.4.	832	292	260	90	170
16.	PANEL 2.6.	711	292	410	30	380
18.	PANEL 2.8.	675	276	280	105	- 1
19.	PANEL 2.9.	325	276	820	15	805

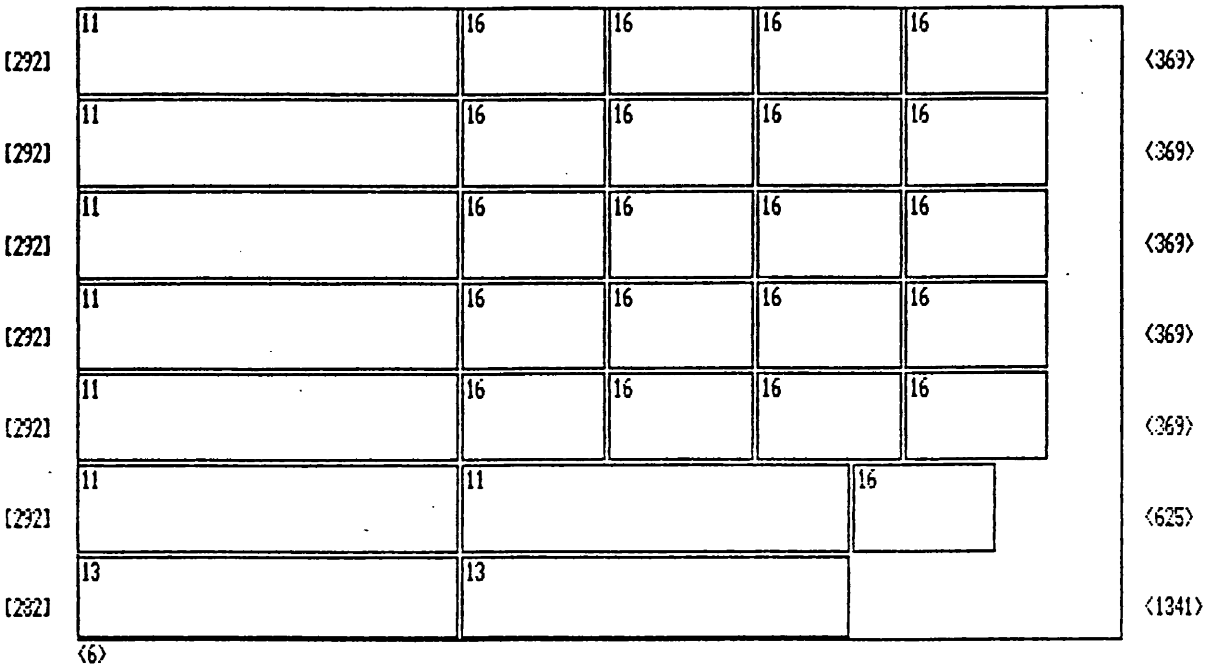
PATTERN NO. : 3.1. GOAL DIRECTION : P (1310)

BOARD SIZE : 5120 x 2070. NO. REQUIRED : 15. WASTE : 7.39 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
11.	PANEL 2.1.	1887	292	300	30	120
14.	PANEL 2.4.	832	292	260	180	- 10
16.	PANEL 2.6.	711	292	410	30	350
19.	PANEL 2.9.	325	276	820	900	- 95

PATTERN NO. : 4.1. GOAL DIRECTION : P (1650)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 18. WASTE : 12.42 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.	
11.	PANEL 2.1.	1887	292	300	126	-	6
16.	PANEL 2.6.	711	292	410	378	-	28
13.	PANEL 2.3.	1887	282	30	36	-	6

F

```
SUMMARY      M2       M3      %/P      %/B
PANELS     548.8     8.23    100.0     87.8
EXTRA       50.7      .76      9.2      8.1
SHEETS     625.3     9.38    113.9    100.0
WASTE       25.8      .39      4.7      4.1

SHEET USAGE
  59 * 5120 X 2070
WHAT NEXT? 3
3-OUTPUT
LAYOUT(0-4)? 1
OPTICUT 110683  TEST # 5.

 L/N LENGTH WIDTH  REQ IDENT   CUT DIFF.       M2       M3 DESCRIPTION
   1  1887   292   300     1   319    19    175.8     2.64 PANEL
   2  1887   292    30     2    30     0     16.5      .25 PANEL
   3  1887   282    30     3    30     0     16.0      .24 PANEL
   4   832   292   260     4   270    10     65.6      .98 PANEL
   5   541   292   160     5   199    39     31.4      .47 PANEL
   6   711   292   410     6   450    40     93.4     1.40 PANEL
   7   437   292   200     7   216    16     27.6      .41 PANEL
   8   675   276   280     8   328    48     61.1      .92 PANEL
   9   325   276   820     9   898    78     80.6     1.21 PANEL
  10   475   276   200    10   241    41     31.6      .47 PANEL
 100  5120  2070  9999    12    59 -9940    625.3     9.38 PANEL
LINE/PLAN DEPENDENCE
  1: 1 3 4 . . 7 . . .
  2: 1 . . . . . . . .
  3: . 3 . . . . . . .
  4: . . 4 . . . . . .
  5: 1 . . . 6 . 8 .10
  6: 1 . 4 . 6 . . 9 .
  7: . . . . . 7 . . .
  8: 1 . 4 . 6 7 8 .10
  9: . . . 5 . . 8 9 .
 10: 1 . 4 5 . 7 . .10
100: 1 3 4 5 6 7 8 910
WHAT NEXT? 3
3-OUTPUT
```

9

```
:-----------------------------------------------------------------------:
:475◆5     PANEL:       :       :675◆4  :    PANEL       :              :(0)
:-X276-------------------------X276-------------------------------------:
:541  :711    :1887◆2                       :                          ::(74)
:-X292:-X292--:-X292------------------------------------------------------::
:  ◆6 :  ◆6   :  ◆6                         :                          ::
:     :       :                             :                          ::
:-----:-------:-----------------------------------------------------------::
:     :       :                             :                          ::
:     :       :                             :                          ::
PANEL-:PANEL--:-------------------PANEL--------------------------------::
:     :       :                             :                          ::
:     :       :                             :                          ::
:-----:-------:-----------------------------------------------------------::
:     :       :                             :                          ::
:     :       :                             :                          ::
:-----:-------:-----------------------------------------------------------::
:     :       :                             :                          ::
:     :       :                             :                          ::
:-----------------------------------------------------------------------:
:-----------------------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	300	1	30	16.5	.25	PANEL
2	1887	292	30	2	30	16.5	.25	PANEL
5	541	292	160	5	30	4.7	.07	PANEL
6	711	292	410	6	30	6.2	.09	PANEL
8	675	276	280	8	20	3.7	.06	PANEL
10	475	276	200	10	25	3.3	.05	PANEL

OPTICUT 110683   TEST # 5.

PLAN 743 14.5 % SAW 1 SHEETS   5 ◆ 5120 X 2070 X 15.0   53.0 M2   .79

```
:-----------------------------------------------------------------------:
:292◆11   :  :    :  :    :  :    :  :    :282◆6 :  :  :   :  :X:(131)
: X1887   :  :    :  :    :  :    :  :    : X1887:  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :  PANEL     :  :    :  :    :  :  PANEL :    :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:  :  :   :  :    :  :    :  :    :  :    :  :   :  :  :   :  :X:
:-----------------------------------------------------------------------:
:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX:
:-----------------------------------------------------------------------:
(178)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	300	1	55	30.3	.45	PANEL
3	1887	282	30	3	30	16.0	.24	PANEL

H

```
OPTICUT 110683   TEST # 5.

PLAN 744   2.6 % SAW 1 SHEETS:  15 ◆ 5120 X 2070 X 15.0   159.0 M2    2.3

  :------------------------------------------------------------:
  :475◆5     PANEL:     :     :675◆4  :    PANEL       :       :(0)
  :-X276------------------------X276---------------------------:
  :711    :832◆3    :         :        :1887                   :(1)
  :-X292--:-X292-----------------------:-X292------------------:
  :  ◆6   :  ◆6     :         :        :  ◆6                   :
  :       :         :         :        :                       :
  :-------:----------------------------:-----------------------:
  :       :         :         :        :                       :
  :       :         :         :        :                       :
  :PANEL--:----------PANEL-------------:-------PANEL-----------:
  :       :         :         :        :                       :
  :       :         :         :        :                       :
  :-------:----------------------------:-----------------------:
  :       :         :         :        :                       :
  :       :         :         :        :                       :
  :-------:----------------------------:-----------------------:
  :       :         :         :        :                       :
  :       :         :         :        :                       :
  :------------------------------------------------------------:
  :------------------------------------------------------------:
 (7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	300	1	90	49.6	.74	PANEL
4	832	292	260	4	270	65.6	.98	PANEL
6	711	292	410	6	90	18.7	.28	PANEL
8	675	276	280	8	60	11.2	.17	PANEL
10	475	276	200	10	75	9.8	.15	PANEL

```
OPTICUT 110683   TEST # 5.

PLAN 745   4.3 % SAW 1 SHEETS    7 ◆ 5120 X 2070 X 15.0    74.2 M2    1.1

  :------------------------------------------------------------:
  :475 ::325◆14:   :   :   :  :   :   :   :   :   :   :   :    :(20)
  :-X276--X276-------------------------------------------------:
  :  ◆5:   ◆5  :   :   :   :  :   :   :   :   :   :   :   :    :
  :    :   :   :   :   :   :  :   :   :   :   :   :   :   :    :
  :----:-------------------------------------------------------:
  PANEL:   :   :   :   :   :  :PANEL  :   :   :   :   :   :    :
  :    :   :   :   :   :   :  :   :   :   :   :   :   :   :    :
  :----:-------------------------------------------------------:
  :    :   :   :   :   :   :  :   :   :   :   :   :   :   :    :
  :----:-------------------------------------------------------:
  :    :   :   :   :   :   :  :   :   :   :   :   :   :   :    :
  :    :   :   :   :   :   :  :   :   :   :   :   :   :   :    :
  :------------------------------------------------------------:
  :276◆18  :   :  :  :   :  :  :   :  :  :  :   :   :  :   :  ::(62)
  : X325:  :   :  :  :   :  :  :   :  :  :  :   :   :  :   :  ::
  :--◆2---------------------PANEL-----------------------------::
  :  :  :  :   :  :  :   :  :  :   :  :  :  :   :   :  :   :  ::
  :  :  :  :   :  :  :   :  :  :   :  :  :  :   :   :  :   :  ::
  :------------------------------------------------------------:
  :------------------------------------------------------------:
 (5)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
9	325	276	820	9	742	66.6	1.00	PANEL
10	475	276	200	10	35	4.6	.07	PANEL

I

PLAN 746 3.9 % SAW 1 SHEETS 2 * 5120 X 2070 X 15.0   21.2 M2   .32

```
:------------------------------------------------------------------:
:276*18  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::(62)
: X675:  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  PANEL  :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:------------------------------------------------------------------:
:541*8:    :      :  PANEL     :      :      :      :711PANEL:(36)
:-X292-------------------------------------------------X292---:
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  :
:292*17    :  :    :  :    :  :    :  :    :  :    :  :    :  ::(71)
: X541:    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:   *2 :   :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:-------------------------PANEL-------------------------------::
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:  :  :    :  :    :  :    :  :    :  :    :  :    :  :    :  ::
:------------------------------------------------------------------:
:------------------------------------------------------------------:
(1)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	541	292	160	5	84	13.3	.20	PANEL
6	711	292	410	6	2	.4	.01	PANEL
8	675	276	280	8	36	6.7	.10	PANEL

OPTICUT 110683 TEST # 5.

PLAN 747 2.8 % SAW 1 SHEETS 12 * 5120 X 2070 X 15.0 127.2 M2   1.91

```
:------------------------------------------------------------------:
:475*5     PANEL:       :      :675*4  :     PANEL       :         :(0)
:-X276-----------------------X276----------------------------------:
:437*3    :     :1887*2                   :                        :(10)
:-X292---------:-X292----------------------------------------------:
:   *6:   :     :  *6                     :                        :
:     :   :     :                         :                        :
:--------------:---------------------------------------------------:
:     :   :     :                         :                        :
:     :   :     :                         :                        :
:---PANEL------:------------------PANEL------------------------------:
:     :   :     :                         :                        :
:     :   :     :                         :                        :
:--------------:---------------------------------------------------:
:     :   :     :                         :                        :
:     :   :     :                         :                        :
:--------------:---------------------------------------------------:
:     :   :     :                         :                        :
:     :   :     :                         :                        :
:------------------------------------------------------------------:
:------------------------------------------------------------------:
(7)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
1	1887	292	300	1	144	79.3	1.19	PANEL
7	437	292	200	7	216	27.6	.41	PANEL
8	675	276	280	8	48	8.9	.13	PANEL
10	475	276	200	10	60	7.9	.12	PANEL

J

```
OPTICUT 110683  TEST # 5.

PLAN 748  3.7 % SAW 1 SHEETS   4 + 5120 X 2070 X 15.0   42.4 M2    .64

  :------------------------------------------------------------:
  :276+18  :   :  :  :   :  :  :   :  :   :  :   :  :  :   :  ::(62)
  : X675:  :   :  :  :   :  :  :   :  :   :  :   :  :  :   :  ::
  :  :  :  :   :  :  :   :  PANEL  :  :   :  :   :  :  :   :  ::
  :  :  :  :   :  :  :   :  :  :   :  :   :  :   :  :  :   :  ::
  :  :  :  :   :  :  :   :  :  :   :  :   :  :   :  :  :   :  ::
  :------------------------------------------------------------:
  :325  :675+7       :       :        :       :       :       ::(30)
  :-X276--X276------------------------------------------------::
  :  +3     +3:      :       :        :       :       :       ::
  PANE       :       :PANEL   :       :       :       :       ::
  :--:--------------------------------------------------------::
  :  :       :       :       :        :       :       :       ::
  :  :       :       :       :        :       :       :       ::
  :------------------------------------------------------------:
  :292+17   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::(71)
  : X541:   :  :   :  :   : PANEL:  :   :  :    :  :   :  :   ::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :------------------------------------------------------------:
  :------------------------------------------------------------:
 (1)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	541	292	160	5	68	10.7	.16	PANEL
8	675	276	280	8	156	29.1	.44	PANEL
9	325	276	820	9	12	1.1	.02	PANEL

```
OPTICUT 110683  TEST # 5.

PLAN 749  4.7 % SAW 1 SHEETS   8 + 5120 X 2070 X 15.0   84.8 M2   1.27

  :------------------------------------------------------------:
  :711+7  :       :        :PANEL  :         :       :       :X:(108)
  :-X292-------------------------------------------------------:
  :276+18  :   :  :  :   :  PANEL  :  :   :  :   :  :  :   :  ::(62)
  : X325:  :   :  :  :   :  :  :   :  :   :  :   :  :  :   :  ::
  :------------------------------------------------------------:
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :    :
  :292+17   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::(71)
  : X711:   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :  +2 :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :------------------------PANEL------------------------------::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
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  :  :  :   :  :   :  :   :  :   :  :   :  :    :  :   :  :   ::
  :------------------------------------------------------------:
  :------------------------------------------------------------:
 (11)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
6	711	292	410	6	328	68.1	1.02	PANEL
9	325	276	820	9	144	12.9	.19	PANEL

K

PLAN 750 3.8 % SAW 1 SHEETS   1 ◆ 5120 X 2070 X 15.0   10.6 M2   .16

```
:-----------------------------------◆-----------------------:
:292◆17   :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::(71)
: X541:   :  :   :  :   : PANEL:  :   :  :   :  :   :  :   ::
:  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::
:  :  :   :  :   :  :   :  :   :  :   :  :   :  :   :  :   ::
:-----------------------------------------------------------:
:675◆4  :       :       :       :475◆5     :    :     :     :(0)
:-X276------PANEL---------------:-X276----PANEL-------------:
:  ◆2   :       :       :       :  ◆2:     :    :     :     :
:       :       :       :       :    :     :    :     :     :
:-----------------------------------------------------------:
:276◆18  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::(62)
: X475:  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  ◆2 :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:------------------------PANEL-----------------------------::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
:  :  :  :   :  :  :   :  :  :   :  :  :  :   :  :  :   :  ::
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:-----------------------------------------------------------:
:-----------------------------------------------------------:
(2)
```

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	M2	M3	DESCRIPTION
5	541	292	160	5	17	2.7	.04	PANEL
8	675	276	280	8	8	1.5	.02	PANEL
10	475	276	200	10	46	6.0	.09	PANEL

OPTICUT 110683 TEST # 5.

L/N	LENGTH	WIDTH	REQ	IDENT	CUT	DIFF.	M2	M3	DESCRIPTION
1	1887	292	300	1	319	19	175.8	2.64	PANEL
2	1887	292	30	2	30	0	16.5	.25	PANEL
3	1887	282	30	3	30	0	16.0	.24	PANEL
4	832	292	260	4	270	10	65.6	.98	PANEL
5	541	292	160	5	199	39	31.4	.47	PANEL
6	711	292	410	6	450	40	93.4	1.40	PANEL
7	437	292	200	7	216	16	27.6	.41	PANEL
8	675	276	280	8	328	48	61.1	.92	PANEL
9	325	276	820	9	898	78	80.6	1.21	PANEL
10	475	276	200	10	241	41	31.6	.47	PANEL
100	5120	2070	9999	12	59	-9940	625.3	9.38	PANEL

LINE/PLAN DEPENDENCE

```
  1: 1 3 4 . . 7 . . .
  2: 1 . . . . . . . .
  3: . 3 . . . . . . .
  4: . . 4 . . . . . .
  5: 1 . . . 6 . 8 .10
  6: 1 . 4 . 6 . . 9 .
  7: . . . . . 7 . . .
  8: 1 . 4 . 6 7 8 .10
  9: . . . 5 . . 8 9 .
 10: 1 . 4 5 . 7 . .10
100: 1 3 4 5 6 7 8 910
```

APPENDIX 4.

This appendix details the computational map of the proposed heuristic approach.For continuity reasons the example used is Test no. 7 from the Comparision Test of Chapter Eight.

The output is well documented so that each step/procedure is able to be followed.

For confidential reasons the details of the strip and pattern knapsack algorithm are omitted at the request of my employer, Joint Consultancy on Patterns and Systems Ltd.

```
A>popmain
Orders were :

Panel width = 396 and total volume is 8120640

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   59    581    396  3000      7020000  PANEL 6.3.
   62    444    396   420       752640  PANEL 6.6.
   61    431    396   200       348000  PANEL 6.5.

Panel width = 581 and total volume is 7502460

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  59    396    581  3000      7020000  PANEL 6.3.
R  58    246    581   330       482460  PANEL 6.2.

Panel width = 444 and total volume is 2257440

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  60    556    444   600      1504800  PANEL 6.4.
R  62    396    444   420       752640  PANEL 6.6.

Panel width = 556 and total volume is 1504800

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   60    444    556   600      1504800  PANEL 6.4.

Panel width = 419 and total volume is 1262900

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   63   2039    419   100       864100  PANEL 6.7.
   57    939    419   100       398800  PANEL 6.1.

Panel width = 2039 and total volume is 864100

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  63    419   2039   100       864100  PANEL 6.7.

Panel width = 246 and total volume is 482460

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   58    581    246   330       482460  PANEL 6.2.

Panel width = 939 and total volume is 398800

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  57    419    939   100       398800  PANEL 6.1.

Panel width = 431 and total volume is 348000

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  61    396    431   200       348000  PANEL 6.5.
```

Notes:

* Orders are read in and sorted by width group, in decending order of volume.

* R indicates panel is rotated.

A

```
A>popmain
Orders were :

Panel width = 396 and total volume is 8120640

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   59    581    396  3000       7020000  PANEL 6.3.
   62    444    396   420        752640  PANEL 6.6.
   61    431    396   200        348000  PANEL 6.5.

Panel width = 581 and total volume is 7502460

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  59    396    581  3000       7020000  PANEL 6.3.
R  58    246    581   330        482460  PANEL 6.2.

Panel width = 444 and total volume is 2257440

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  60    556    444   600       1504800  PANEL 6.4.
R  62    396    444   420        752640  PANEL 6.6.

Panel width = 556 and total volume is 1504800

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   60    444    556   600       1504800  PANEL 6.4.

Panel width = 419 and total volume is 1262900

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   63   2039    419   100        864100  PANEL 6.7.
   57    939    419   100        398800  PANEL 6.1.

Panel width = 2039 and total volume is 864100

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  63    419   2039   100        864100  PANEL 6.7.

Panel width = 246 and total volume is 482460

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
   58    581    246   330        482460  PANEL 6.2.

Panel width = 939 and total volume is 398800

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  57    419    939   100        398800  PANEL 6.1.

Panel width = 431 and total volume is 348000

 No  length  width  qty       volume   name
 ==  ======  =====  ===       ======   ====
R  61    396    431   200        348000  PANEL 6.5.
```

Notes:

* Orders are read in and sorted by width group, in decending order of volume.

* R indicates panel is rotated.

The following widths were considered for inclusion on the board

400	585	448	560	423	2043	250	943	435

and the following combinations were found

5	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0
1	2	1	0	0	0	0	0	0
0	2	2	0	0	0	0	0	0
0	1	2	1	0	0	0	0	0
0	0	2	2	0	0	0	0	0
4	0	0	0	1	0	0	0	0
1	2	0	0	1	0	0	0	0
3	0	1	0	1	0	0	0	0
0	2	1	0	1	0	0	0	0

Strip wid = 396, length = 5124
Panel lengths :

585	448	435

The combinations found :

7	2	0
4	6	0
1	10	0
0	11	0
8	0	1
7	1	1
4	5	1
1	9	1
7	0	2
4	4	2
1	8	2
4	3	3
1	7	3
5	1	4
4	2	4
1	6	4
5	0	5
4	1	5
1	5	5
4	0	6
2	3	6
1	4	6
2	2	7
1	3	7
2	1	8

Notes:

* The first 'n' width groups are now considered for inclusion onto a board.

* 'n' is a parameter defined in the programme.

* Width = width + saw thickness.
  400 = (396 + 4).

* Panel length combinations are computed for each width group.

C

```
Merit calcs :

Actual wastage   133   96   59  196    9  146  109   72  159  122   85  135   98   11  148  111   24  161  124
174    0  137   13  150   26

Waste penalty  -259 -187 -115 -382  -17 -284 -212 -140 -310 -238 -165 -263 -191  -21 -288 -216  -46 -314 -241 -3
39    0 -267  -25 -292  -50
Diversity reward   200  200  200  100  200  300  300  300  200  300  300  300  300  300  300  300  200  300  300
  200  300  300  300  300  300
Penalty for open orders  -100 -100 -100    0 -108 -200 -200 -200 -100 -292 -206 -200 -280 -200 -200 -244 -100 -200
  -200 -100 -200 -200 -200 -200 -200
Reward for closure   12   12   12   12   12   12   12   12   12   12   12   12   12   12   12   12   12   12   1
2   12   12   12   12   12   12
Z_cutting penalty    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0

Actual merit figure   853  925  997  730 1087  828  900  972  802  782  941  849  841 1091  824  852 1066  798  8
71  773 1112  845 1087  820 1062

Storing strip 21
Storing strip 14
Storing strip 5
Storing strip 23
Storing strip 17
```

Notes:

* For each width-panel combination set, a figure of merit is calculated; The top five figure of merit strips, for this width, are stored in a width strip memory.

* This example is for width strip 396.

D

Figure of merit calculations for strip width 581.

```
Strip wid = 581, length = 5124
Panel lengths :
   400   250

The combinations found :
     12      0
     12      1
     11      2
     10      3
     10      4
      9      5
      9      6
      8      7
      7      8
      7      9
      6     10
      5     11
      5     12
      4     13
      4     14
      3     15
      2     16
      2     17
      1     18
      0     19
      0     20


Merit calcs :

Actual wastage    324    74   224   374   124   274    24   174   324    74   224   374   124   274    24   174   324    74   224
374   124

Waste penalty   -632  -144  -437  -729  -241  -534   -46  -339  -632  -144  -437  -729  -241  -534   -46  -339  -632  -144  -437
29  -241
Diversity reward   100   200   200   200   200   200   200   200   200   200   200   200   200   200   200   200   200   200   2
  100   100
Penalty for open orders      0  -152  -122  -100  -100  -100  -100  -100  -100  -100  -100  -100  -100  -100  -100  -100  -100   -
  -100     0     0
Reward for closure     12    12    12    12    12    12    12    12    12    12    12    12    12    12    12    12    12    12
2    12    12
Z_cutting penalty      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0

Actual merit figure    480   916   653   383   871   578  1066   773   480   968   675   383   871   578  1066   773   480   968
75   383   871

Storing strip 7
Storing strip 15
Storing strip 10
Storing strip 18
Storing strip 2
```

Figure of merit calculations for strip width 444.

```
Strip wid = 444, length = 5124
Panel lengths :
  560  400

The combinations found :
     9    0
     8    1
     7    2
     7    3
     6    4
     5    5
     4    6
     4    7
     3    8
     2    9
     2   10
     1   11
     0   12
```

Merit calcs :

Actual wastage	84	244	404	4	164	324	484	84	244	404	4	164	324
Waste penalty	-163	-476	-788	-7	-320	-632	-944	-163	-476	-788	-7	-320	-632
Diversity reward	100	200	200	200	200	200	200	200	200	200	200	200	100
Penalty for open orders	0	-100	-100	-124	-192	-140	-100	-100	-100	-100	-100	-100	0
Reward for closure	12	12	12	12	12	12	12	12	12	12	12	12	12
Z_cutting penalty	0	0	0	0	0	0	0	0	0	0	0	0	0
Actual merit figure	949	636	324	1081	700	440	168	949	636	324	1105	792	480

Storing strip 11
Storing strip 4
Storing strip 1
Storing strip 8
Storing strip 12

F

```
Strip wid = 556, length = 5124
Panel lengths :
   448

The combinations found :
    11


Merit calcs :

Actual wastage    196

Waste penalty   -382
Diversity reward    100
Penalty for open orders      0
Reward for closure     12
Z_cutting penalty      0

Actual merit figure    730

Storing strip 1
```

Figure of merit calculations for strip width 556.

Figure of merit calculations for strip width 419.

```
Strip wid = 419, length = 5124
Panel lengths :
  2043   943

The combinations found :
     2     1
     1     3
     0     5


Merit calcs :

Actual wastage     95   252   409

Waste penalty   -185  -491  -798
Diversity reward     200   200   100
Penalty for open orders    -100  -100     0
Reward for closure      12     12     12
Z_cutting penalty      0      0      0

Actual merit figure    927    621    314

Storing strip 1
Storing strip 2
Storing strip 3
```

H

PATTERN GENERATION:

From the strip memory, the strip width combinations are now computed. For each cutting pattern generated a figure of merit is calculated from the following:

A - 10464560 :	area utilization of board.
R - 21:	Run length for this pattern; note there is a further internal calculation to reduce the run length, subject to the extra's permitted and hence this is the maximum run-length required.
S - 1	Single stagger pattern.
WP - Waste Penalty:	The area figure in (A), is transposed to a value scale.
DR - Diversity Reward:	A reward to discourage single panel type patterns.
CR - Closure Reward:	A reward to encourage cutting patterns which have multiple closures.
AR - Appear Reward:	Reward given so that panels which have already appeared will be closed as early as possible: subject to parameterized value trade-off against waste, in programme.
OP - Open Order Penalty:	Penalty to discourage new panel types being added to the current cutting pattern: subject to parameterized vale trade-off against waste in programme.
ZP - Z -Cut Penalty) HP - H -Cut Penalty) BP - Board Change) Penalty)	Penalties to ensure that changes in pattern complexity result in significant gains either in closure or waste reduction.

```
Storing pattern at position 1
400,1 : 400,1 : 400,1 : 400,1 : 400,1 : A=10137600 : R=7 : S=0 : WP=-92 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=[illegible]
1
Storing pattern at position 1
400,1 : 400,1 : 400,1 : 400,1 : 400,2 : A=10133244 : R=8 : S=1 : WP=-92 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=122
1
Storing pattern at position 1
400,1 : 400,1 : 400,1 : 400,1 : 400,3 : A=10134036 : R=8 : S=2 : WP=-92 : DR=-16 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=122
2
Storing pattern at position 2
400,1 : 400,1 : 400,1 : 400,2 : 400,2 : A=10128888 : R=8 : S=1 : WP=-93 : DR=-16 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=122
1
Storing pattern at position 5
400,1 : 400,1 : 400,1 : 400,2 : 400,3 : A=10129680 : R=9 : S=2 : WP=-93 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=122
0
400,1 : 400,1 : 400,1 : 400,3 : 400,3 : A=10130472 : R=10 : S=2 : WP=-93 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
19
400,1 : 400,1 : 400,2 : 400,2 : 400,2 : A=10124532 : R=9 : S=1 : WP=-94 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
9
400,1 : 400,1 : 400,2 : 400,2 : 400,3 : A=10125324 : R=10 : S=2 : WP=-94 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
18
400,1 : 400,1 : 400,2 : 400,3 : 400,3 : A=10126116 : R=12 : S=2 : WP=-94 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
16
400,1 : 400,1 : 400,3 : 400,3 : 400,3 : A=10126908 : R=14 : S=2 : WP=-94 : DR=-22 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
14
400,1 : 400,2 : 400,2 : 400,2 : 400,2 : A=10120176 : R=10 : S=1 : WP=-95 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
17
400,1 : 400,2 : 400,2 : 400,2 : 400,3 : A=10120968 : R=11 : S=2 : WP=-95 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
15
400,1 : 400,2 : 400,2 : 400,3 : 400,3 : A=10121760 : R=13 : S=2 : WP=-95 : DR=-22 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
13
400,1 : 400,2 : 400,3 : 400,3 : 400,3 : A=10122552 : R=16 : S=2 : WP=-94 : DR=-25 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
11
400,1 : 400,3 : 400,3 : 400,3 : 400,3 : A=10123344 : R=21 : S=2 : WP=-94 : DR=-29 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
07
400,2 : 400,2 : 400,2 : 400,2 : 400,2 : A=10115820 : R=10 : S=0 : WP=-96 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
14
400,2 : 400,2 : 400,2 : 400,2 : 400,3 : A=10116612 : R=12 : S=1 : WP=-96 : DR=-23 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
11
400,2 : 400,2 : 400,2 : 400,2 : 400,4 : A=10115028 : R=9 : S=2 : WP=-96 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
5
400,2 : 400,2 : 400,2 : 400,3 : 400,3 : A=10117404 : R=15 : S=1 : WP=-95 : DR=-26 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
09
400,2 : 400,2 : 400,2 : 400,3 : 400,4 : A=10115820 : R=10 : S=2 : WP=-96 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
14
400,2 : 400,2 : 400,2 : 400,4 : 400,4 : A=10114236 : R=8 : S=2 : WP=-96 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
6
400,2 : 400,2 : 400,3 : 400,3 : 400,3 : A=10118196 : R=19 : S=1 : WP=-95 : DR=-29 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
06
400,2 : 400,2 : 400,3 : 400,3 : 400,4 : A=10116612 : R=12 : S=2 : WP=-96 : DR=-23 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
11
400,2 : 400,2 : 400,3 : 400,4 : 400,4 : A=10115028 : R=9 : S=2 : WP=-96 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
5
400,2 : 400,2 : 400,4 : 400,4 : 400,4 : A=10113444 : R=7 : S=2 : WP=-96 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
6
400,2 : 400,3 : 400,3 : 400,3 : 400,3 : A=10118988 : R=26 : S=1 : WP=-95 : DR=-34 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
01
400,2 : 400,3 : 400,3 : 400,3 : 400,4 : A=10117404 : R=15 : S=2 : WP=-95 : DR=-26 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
09
400,2 : 400,3 : 400,3 : 400,4 : 400,4 : A=10115820 : R=10 : S=2 : WP=-96 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
14
400,2 : 400,3 : 400,4 : 400,4 : 400,4 : A=10114236 : R=8 : S=2 : WP=-96 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
6
400,2 : 400,4 : 400,4 : 400,4 : 400,4 : A=10112652 : R=7 : S=2 : WP=-96 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
```

J

400,3 : 400,3 : 400,3 : 400,3 : 400,4 : A=10118196 : R=19 : S=1 : WP=-95 : DR=-29 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
06
400,3 : 400,3 : 400,3 : 400,3 : 400,5 : A=10113840 : R=23 : S=2 : WP=-96 : DR=-34 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
00
400,3 : 400,3 : 400,3 : 400,4 : 400,4 : A=10116612 : R=12 : S=1 : WP=-96 : DR=-23 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
11
400,3 : 400,3 : 400,3 : 400,4 : 400,5 : A=10112256 : R=14 : S=2 : WP=-96 : DR=-26 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
08
400,3 : 400,3 : 400,3 : 400,5 : 400,5 : A=10107900 : R=16 : S=2 : WP=-97 : DR=-30 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
03
400,3 : 400,3 : 400,4 : 400,4 : 400,4 : A=10115028 : R=9 : S=1 : WP=-96 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
5
400,3 : 400,3 : 400,4 : 400,4 : 400,5 : A=10110672 : R=10 : S=2 : WP=-97 : DR=-21 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
12
400,3 : 400,3 : 400,4 : 400,5 : 400,5 : A=10106316 : R=11 : S=2 : WP=-98 : DR=-23 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
09
400,3 : 400,3 : 400,5 : 400,5 : 400,5 : A=10101960 : R=12 : S=2 : WP=-98 : DR=-27 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
05
400,3 : 400,4 : 400,4 : 400,4 : 400,4 : A=10113444 : R=7 : S=1 : WP=-96 : DR=-18 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
6
400,3 : 400,4 : 400,4 : 400,4 : 400,5 : A=10109088 : R=8 : S=2 : WP=-97 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
4
400,3 : 400,4 : 400,4 : 400,5 : 400,5 : A=10104732 : R=8 : S=2 : WP=-98 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
2
400,3 : 400,4 : 400,5 : 400,5 : 400,5 : A=10100376 : R=9 : S=2 : WP=-99 : DR=-22 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=120
9
400,3 : 400,5 : 400,5 : 400,5 : 400,5 : A=10096020 : R=10 : S=2 : WP=-99 : DR=-24 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
07
400,4 : 400,4 : 400,4 : 400,4 : 400,4 : A=10111860 : R=6 : S=0 : WP=-96 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
4
400,4 : 400,4 : 400,4 : 400,4 : 400,5 : A=10107504 : R=7 : S=1 : WP=-97 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
4
400,4 : 400,4 : 400,4 : 400,5 : 400,5 : A=10103148 : R=7 : S=1 : WP=-98 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
3
400,4 : 400,4 : 400,5 : 400,5 : 400,5 : A=10098792 : R=7 : S=1 : WP=-99 : DR=-20 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=121
1
400,4 : 400,5 : 400,5 : 400,5 : 400,5 : A=10094436 : R=8 : S=1 : WP=-100 : DR=-21 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
09
400,5 : 400,5 : 400,5 : 400,5 : 400,5 : A=10090080 : R=8 : S=0 : WP=-101 : DR=-23 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
06
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8
Storing pattern at position 1
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1
Storing pattern at position 2
400,1 : 400,1 : 400,1 : 400,2 : 448,1 : A=10377228 : R=10 : S=2 : WP=-47 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
68
Storing pattern at position 2
400,1 : 400,1 : 400,2 : 400,2 : 448,1 : A=10372872 : R=10 : S=2 : WP=-47 : DR=-14 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
69
Storing pattern at position 5
400,1 : 400,2 : 400,2 : 400,2 : 448,1 : A=10368516 : R=12 : S=2 : WP=-48 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
67
400,2 : 400,2 : 400,2 : 400,2 : 448,1 : A=10364160 : R=13 : S=1 : WP=-49 : DR=-16 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
65
400,2 : 400,2 : 400,2 : 400,2 : 448,2 : A=10364160 : R=13 : S=2 : WP=-49 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
66
400,2 : 400,2 : 400,2 : 400,3 : 448,1 : A=10364952 : R=16 : S=2 : WP=-49 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
64
400,2 : 400,2 : 400,3 : 400,3 : 448,1 : A=10365744 : R=21 : S=2 : WP=-49 : DR=-19 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
62
400,2 : 400,3 : 400,3 : 400,3 : 448,1 : A=10366536 : R=30 : S=2 : WP=-49 : DR=-22 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
59

K

```
Storing pattern at position 1
585,1 : 585,1 : 448,1 : 448,1 : A=10464560 : R=21 : S=1 : WP=-30 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1285
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Storing pattern at position 2
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Storing pattern at position 2
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Storing pattern at position 3
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Storing pattern at position 1
585,2 : 585,2 : 448,1 : 448,2 : A=10464560 : R=12 : S=2 : WP=-30 : DR=-13 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1287
Storing pattern at position 3
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585,2 : 585,3 : 448,1 : 448,1 : A=10435510 : R=15 : S=2 : WP=-36 : DR=-14 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1280
585,3 : 585,3 : 448,1 : 448,1 : A=10406460 : R=19 : S=1 : WP=-41 : DR=-13 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1276
585,3 : 585,3 : 448,1 : 448,2 : A=10406460 : R=19 : S=2 : WP=-41 : DR=-12 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1277
585,3 : 585,3 : 448,2 : 448,2 : A=10406460 : R=19 : S=2 : WP=-41 : DR=-13 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1276
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585,4 : 585,4 : 448,1 : 448,2 : A=10406460 : R=10 : S=2 : WP=-41 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1274
585,4 : 585,4 : 448,2 : 448,2 : A=10406460 : R=10 : S=2 : WP=-41 : DR=-17 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1272
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585,2 : 448,1 : 448,1 : 560,1 : A=10241528 : R=21 : S=2 : WP=-72 : DR=-14 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1244
585,3 : 448,1 : 448,1 : 560,1 : A=10212478 : R=21 : S=2 : WP=-78 : DR=-13 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1239
585,4 : 448,1 : 448,1 : 560,1 : A=10212478 : R=20 : S=2 : WP=-78 : DR=-14 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1238
585,5 : 448,1 : 448,1 : 560,1 : A=10212478 : R=21 : S=2 : WP=-78 : DR=-15 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1237
448,1 : 448,1 : 560,1 : 560,1 : A=10018496 : R=21 : S=1 : WP=-114 : DR=-24 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1192
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448,3 : 448,4 : 560,1 : 560,1 : A=9947456 : R=18 : S=2 : WP=-127 : DR=-34 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1169
448,4 : 448,4 : 560,1 : 560,1 : A=9947456 : R=20 : S=1 : WP=-127 : DR=-27 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1176
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448,5 : 448,5 : 560,1 : 560,1 : A=9876416 : R=20 : S=1 : WP=-141 : DR=-22 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=1167
Storing pattern at position 1
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54
400,3 : 400,3 : 400,3 : 400,3 : 423,2 : A=10135516 : R=36 : S=2 : WP=-92 : DR=-25 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
13
400,5 : 400,5 : 400,5 : 400,5 : 423,1 : A=10177539 : R=10 : S=1 : WP=-84 : DR=-16 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
30
400,5 : 400,5 : 400,5 : 400,5 : 423,2 : A=10111756 : R=10 : S=2 : WP=-97 : DR=-16 : CR=330 : AR=0 : OP=0 : ZP=0 : HP=0 : BP=0 : M=12
17
```
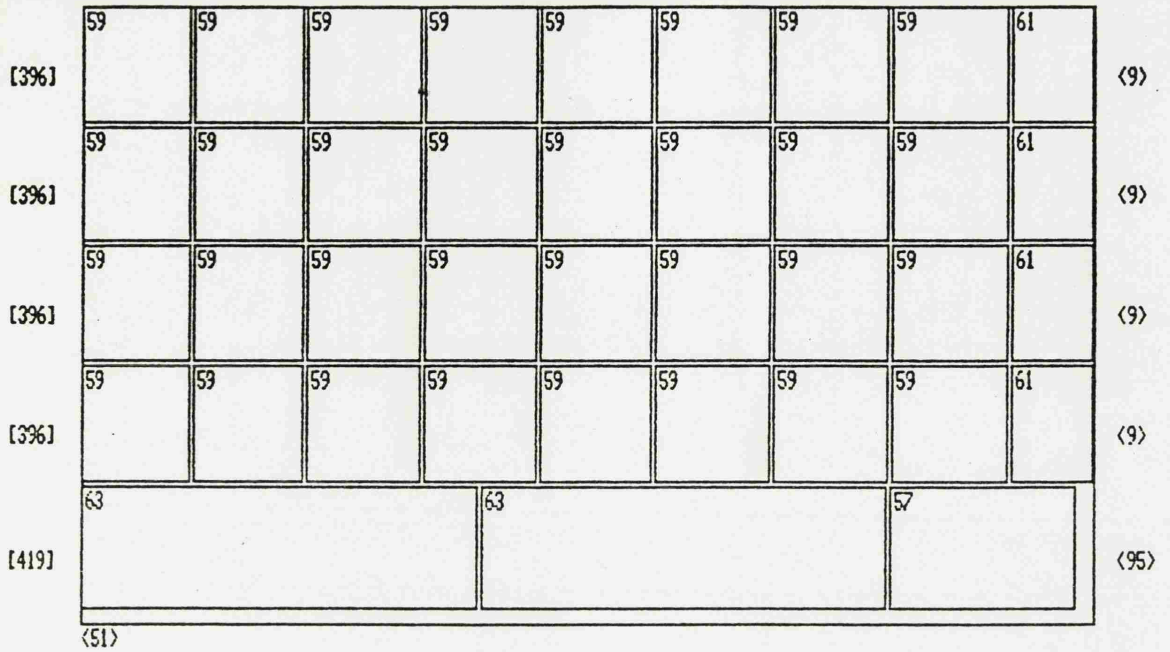
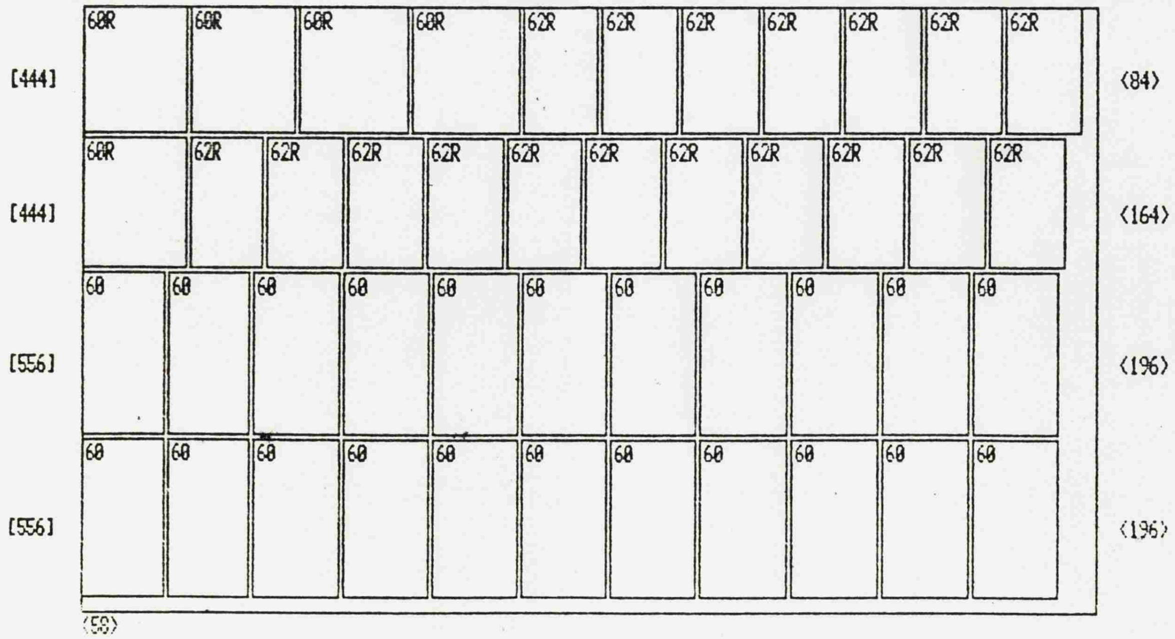

PATTERN NO. : 1.1. GOAL DIRECTION : P (1554)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 50. WASTE : 4.25 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	1600	1400
61.	PANEL 6.5.	431	396	200	200	0
63.	PANEL 6.7.	2039	419	100	100	0
57.	PANEL 6.1.	939	419	100	50	50

PATTERN NO. : 1.2. GOAL DIRECTION : P (1502)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 23. WASTE : 7.24 %

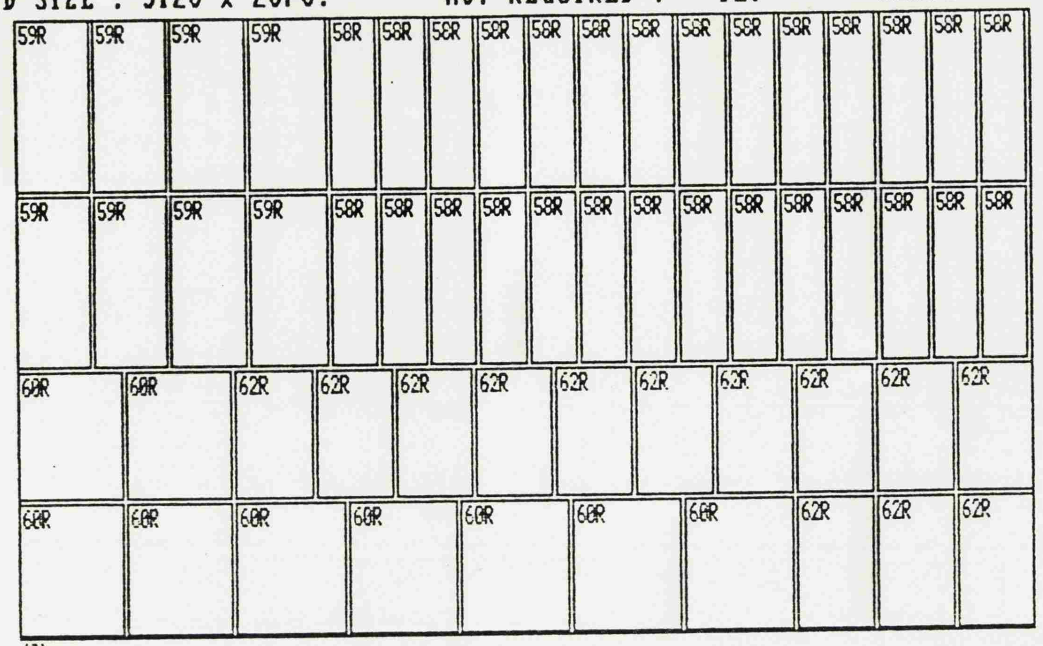


No	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
60.	PANEL 6.4	444	[illegible]	[illegible]	[illegible]	21
62.	PANEL 6.6.	444	396	420	414	[illegible]

M

PATTERN NO. : 1.3. GOAL DIRECTION : P (1287)

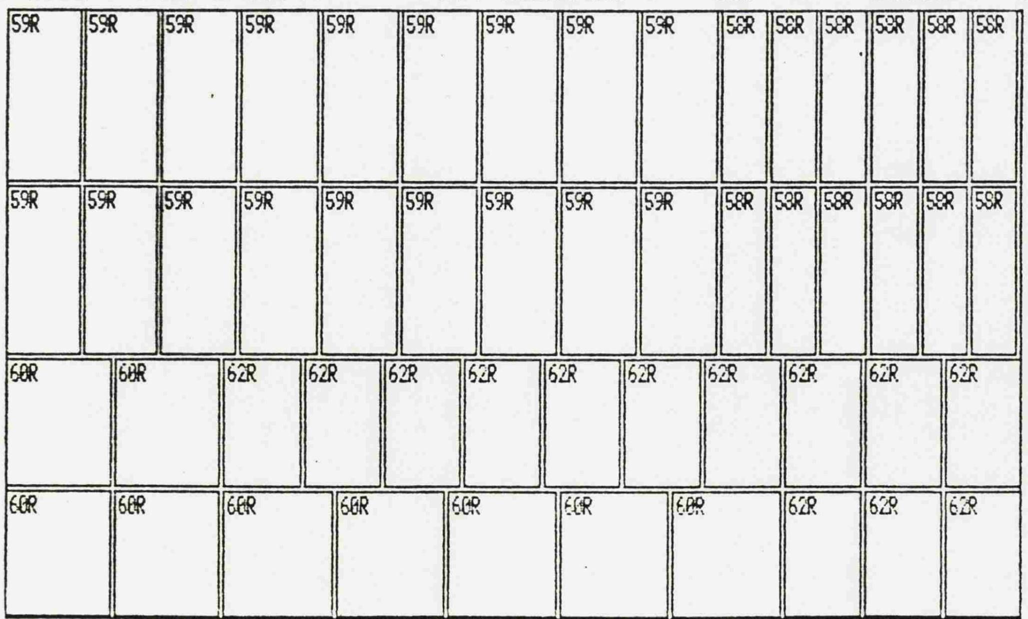
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 12. WASTE : 2.34 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	96	2904
58.	PANEL 6.2.	581	246	330	336	- 6
60.	PANEL 6.4.	444	556	600	108	492
62.	PANEL 6.6.	444	396	420	156	264

PATTERN NO. : 1.4. GOAL DIRECTION : P (1287)

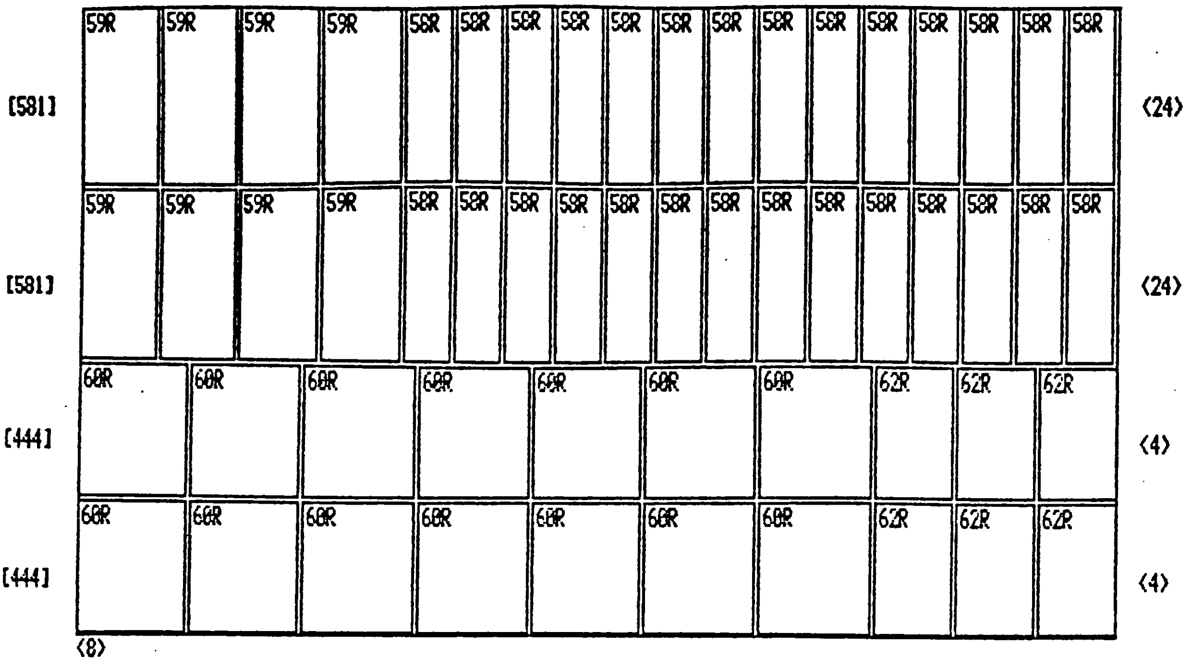
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 28. WASTE : 2.21 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	504	2496
58.	PANEL 6.2.	581	246	330	336	- 6
60.	PANEL 6.4.	444	556	600	252	348
62.	PANEL 6.6.	444	396	420	364	56

N

PATTERN NO. : 1.5. GOAL DIRECTION : P (1286)
BOARD SIZE : 5120 x 2070. NO. REQUIRED : 12. WASTE : 2.31 %



No.	Description / Code	Length	Width	No.Req.	No.Cut	RQ.
59.	PANEL 6.3.	581	396	3000	96	2904
58.	PANEL 6.2.	581	246	330	336	- 6
60.	PANEL 6.4.	444	556	600	168	432
62.	PANEL 6.6.	444	396	420	72	348

******* PUBLISHED PAPERS *******

[1]. The Third Dimension of Two Dimensional Cutting:

OMEGA. The Int.Jl of Mgmt Sci.Vol 10.No.1 pp 81 to 87 1982.

OMEGA The Int. Jl of Mgmt Sci. Vol. 10, No. 1, pp. 81 to 87, 1982
Printed in Great Britain.

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The Third Dimension of Two-Dimensional Cutting

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A number of papers in Operational Research literature have described and discussed approaches to one and two dimensional cutting stock, or trim loss problems; only a handful describe implementation in an industrial setting. It seems that in this area of Operational Research, as in many others, implementation lags far behind theory. In this paper, written jointly by the client and the researcher, we suggest that there is an equally important 'third dimension' concerned with practical and interpersonal issues which is often overlooked in tackling cutting stock problems. We describe work with an international timber company who were concerned about this issue because they were attempting to market a waste cutting optimisation computer package for the furniture and packing case industries. To explore the issue we used techniques developed by our research group at the University of Bath, UK, including an interactive software package called COPE which is designed to assist in the exploration of complex decision making issues.

INTRODUCTION

A NUMBER of commercial computer packages for calculating minimum waste cutting patterns for cutting stock now exist, and have been used primarily in the glass, steel, and paper industries. The client in this project was the head of research of an international timber company who approached the research group at the University of Bath for assistance. The company had produced their own commercial package for waste cutting optimisation, but had encountered considerable difficulty in implementing the package in the UK. The client was anxious to explore the issues in depth in an attempt to resolve some of the confusion which surrounded the topic. For the researchers it offered an interesting opportunity to use a particular approach to looking at complex issues, in relation to a topic which has already received a considerable amount of attention from technical and theoretical operational researchers. It was agreed with the client that he would commit himself to a series of 1–2 hr sessions with the researchers, focussing initially on how he viewed the two dimensional cutting stock problem, and gradually exploring and building up a model of the issues as he saw them. This explicit model would then be the basis for devising policies and strategies to tackle problems experienced in implementation.

BACKGROUND

(1) *Trim loss:*

The two dimensional cutting stock problem in the UK furniture industry involves the conversion (usually called primary conversion) of large stock boards (5–10 M2) of composite wood material (e.g. chipboard and flaxboard), into smaller 'sized' panels which are then

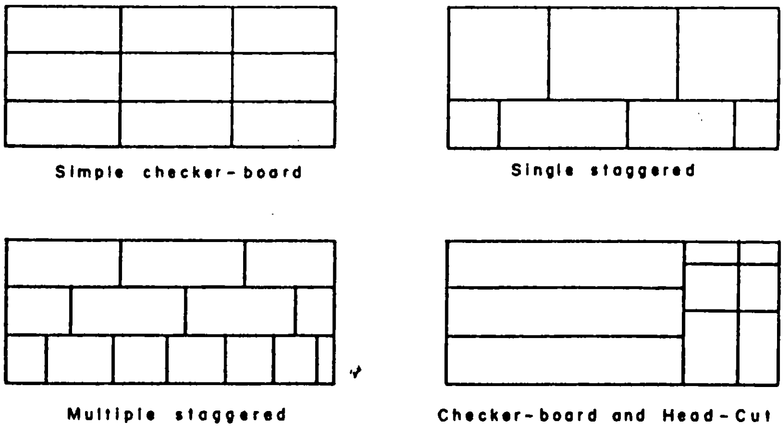

FIG. 1. *Typical pattern types available to the planner in the furniture and packing case industries.*

assembled into units of furniture [12]. Saw cutting technology and constraints of labour costs restrict the cutting patterns to rectangular guillotine cuts. The cutting is usually a two stage process of cutting the board into length strips and cross cutting the strips into the required panels (some off-line cutting is also allowed). Figure 1 gives some indication of the type of patterns cut, which can be of a wide range of complexity from simple checker-board to more complex staggered and head cut patterns. The full details of the package used by the Company are not essential to this paper, and are not provided for obvious commercial reasons. The techniques employed are similar in broad outline to the strip generation heuristics and optimisation described, for example, by Adamowicz & Albano [3].

(2) *UK Furniture and packing case industries*

In the last 20 years, the UK furniture industry has undergone a tremendous change from small, craft based, family businesses to large manufacturing concerns with turnovers in the region of £4–80 million. Throughout the 1960s and early 1970s they operated in a high growth market with consequent emphasis on volume production. The more recent steep rises in labour and material costs now coupled with a decline in demand for their products has heralded a change in production philosophy, and a new emphasis for them, and those who supply them with raw materials, on the cost of waste. Yet despite these pressures very few companies in the UK have explored modern computer based solutions to the waste problem, and a number of those that have, have abandoned the attempt in the early stages.

The client in this project believed the reason for this was that many people took too simple a view of the issue. Yet he was concerned that he did not feel that he was able to 'get on top' of the issue, or to devise strategies for testing out his theories. The feeling that something needs looking at, and under the pressures of working life being able to do it, are two different things. As he later described it: "It isn't that I didn't know the problem areas, rather the problem was unmanageable; too large to view in one visual pass...."

MODELS OF THINKING

Eden *et al.* [5] have argued that an important and often neglected part of tackling a complex issue is to gradually make aspects of the individual beliefs around that issue explicit, so that they may be more carefully and systematically examined. As many OR workers know, the most difficult part of a project is often "knowing how to think about what to think about" [16]. Jackson suggests the use of an exploratory scenario to help with this stage, in which the decision maker begins by letting his mind 'run loose', talking about and writing down ideas on possible strategies and outcomes. Whilst in theory this is a good starting point, in practice the process of thinking aloud, of making ideas, hunches and beliefs explicit is one which most people find difficult to do effectively, unaided. It is also difficult to record the data produced, in a form which allows it to be easily managed.

The client had on a number of occasions attempted to 'think through' the issues on his own, but each time felt he had been unable to sort out the themes and issues as he would have liked. Thus, a series of meetings was arranged with the client in which considerable attention was paid to this 'thinking aloud' problem formulation stage. A central part of the aid was a computer package called COPE (Cognitive Policy Evaluation), which has been developed at Bath University and is designed to assist individuals and groups to think about and explore complex issues. It has now been successfully used in a number of different environments and for a variety of purposes [7]. Fundamental to COPE is the construction of a cognitive map, which is a graphical representation of ideas and beliefs for an individual or group, and the links between them. The map contains concepts, causal links and associative (connotative) links (cognitive maps are described in more detail in Fig. 2). The map is developed through a process of discussion and feedback with the participant until he feels that it is an adequate (requisite) model of his thinking around the issue, and one which he would be prepared to use [6]. The cognitive map can be displayed and manipulated via the COPE software. The software offers an easily changed and explored qualitative representation of a set of ideas. Part of one of the maps developed with the client is shown in Fig. 2.

ADVENTURE IN PROBLEM FORMULATION: WAYS OF MANAGING 'MESSES'

Problem formulation is an ill-used word in this context since it connotes a definite, clear-cut stage of a process, and like other categor-

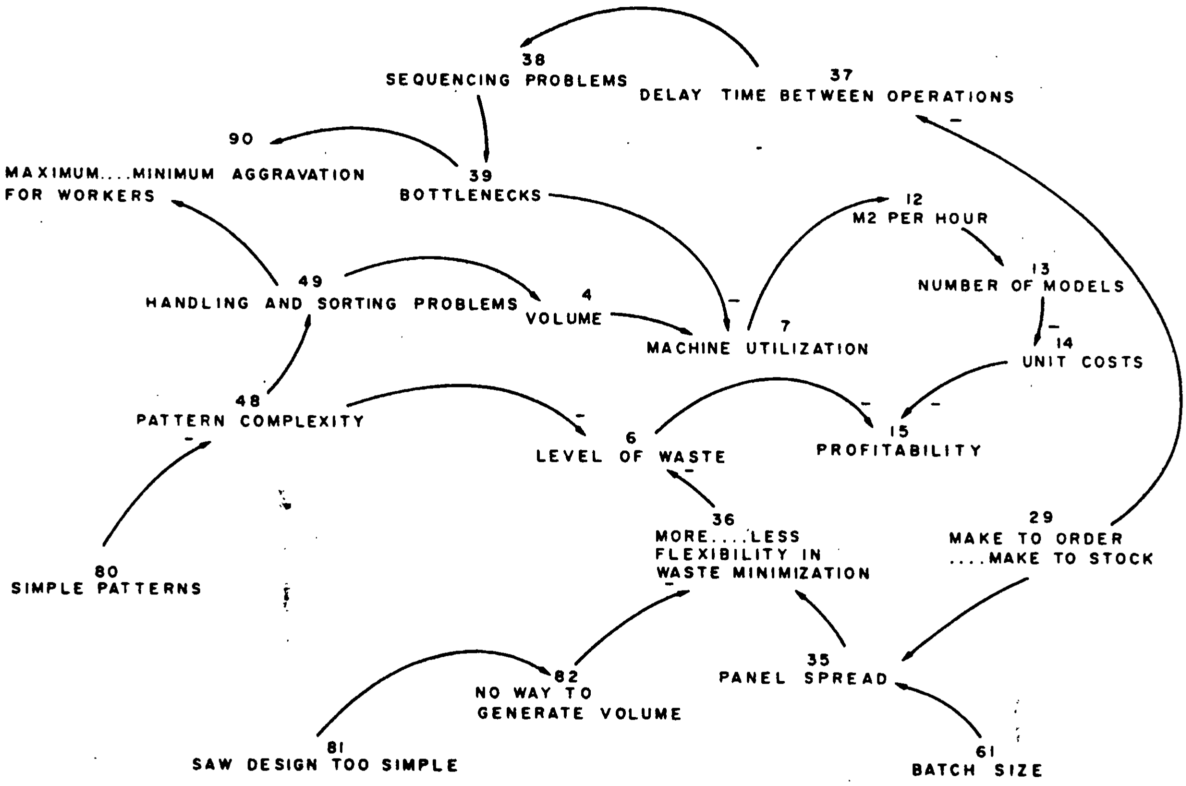

FIG. 2. *A cognitive map contains concepts linked by signed arrows. The arrows indicate that one concept leads to or has some effect on another concept. Concepts are essentially in two complementary parts. These parts (or poles) may be explicit as in 'Maximum.... Minimum aggravation for workers', or implied as in 'An increase in.... A decrease in Pattern Complexity'. A positive arrow (no sign) indicates that the first pole of one concept leads to the first pole of another concept, and that the second pole of a concept leads to the second pole of another concept, as in 'An increase in Handling and Sorting problems' leads to 'Maximum aggravation for workers'. A negative arrow (minus sign) indicates that the first pole of a concept leads to the second pole of another concept, and vice versa. The map is a representation of an individual's beliefs and theories and attempts to reflect the idiomatic expression of the client.*

ized descriptions of OR tends to ignore the confused anxiety producing state which often characterises 'having a problem'. The client in this project apparently faced something more akin to an Ackoffian 'mess' rather than a single problem, as Fig. 2 illustrates. To tackle a 'mess' Ackoff suggests, different approaches are required. It is no longer helpful to isolate single problems from within the 'mess' and attempt to solve each of these independently, for to do this is to ignore the links between problems which create the essential characteristics of the 'mess' [1, 2]. A way of managing 'messes' was needed. This section outlines how this was attempted in more detail, since although Ackoff urges operational researchers to undefine OR and begin to manage 'messes', there is little guide to the practitioner on how to go about this. Whilst the following is by no means ideal, it may provide some insights on how managing 'messes' is different from solving problems.

At each session with the client a wide range of aids was available, including tape recorder, flip chart, blackboard, adhesive labels, and computer terminals. A typical session involved an initial ramble around the topic, with significant concepts and links being drawn on the blackboard or flipchart. This encouraged further elaboration and exploration around these concepts, which could be added to the chart. The chains of related concepts were then transferred to the computer model via a VDU. Exploration of the computer model as amended would reveal how the new chain linked to previously created parts of the model, and often highlighted errors in the researchers listening and interpretation, which could be quickly corrected. More significantly new links and ideas often came out of examining the model interactively in this way. As the model became more complex, the graphics and hard copy terminals were used to focus on specific portions of the model (cognitive map), and the client could take copies away with him to consider in more detail outside the session.

The maps produced by the graphics and hard copy terminals are similar in form to the one shown in Fig. 2. On a visual display unit the concepts can also be presented as linked text as in an increase in 'level of waste' can lead to a decrease in 'profitability'. By entering simple commands the user can, for example, explore the consequences of a concept such as 'an increase in level of waste' for other concepts in the model; look for other concepts which may be similar; group together all concepts which explain 'an increase in level of waste'; and so gradually explore the implications of this concept in the context of the whole model. Analytical facilities for tracing feedback loops, clustering parts of the model, and looking for conflicting explanations and consequences are also available through the computer software. In this project, for instance, the issues discussed in the next section such as the impact of 'pattern complexity' on workers jobs, were developed from explorations of the concept 'pattern complexity' in terms of the model. A further helpful step, for the client, was the ability by studying a large map (150 concepts) to see that some of his concepts related to marketing philosophy, and others to more specific production issues. This distinction 'stood out' when these concepts were seen side by side on a single map, and enabled him to consider the ways in which the overall manufacturing process was affected by marketing decisions.

The whole process is one of gradually and carefully dumping out ideas in a way that makes them readily available for exploration. The client is freed to some extent from the cognitive strain of 'having to hold everything in my head at once', and can thus spend more time considering each portion of the map, knowing that links to other areas are recorded by the software. The grouping and hierarchy analysis procedures available were particularly useful in this instance for identifying areas of the maps which related to specific issues, and revealing the links between that area and other problem areas.

A crucial part of the process was the ability to interact continuously with the model as it developed, and explore the impact of changes during the model building process. The ability to make rapid changes in the structure as well as the content of a model, and to visually feedback the change to the client immediately, is being increasingly recognized as a vital feature to generating good understanding between client and consultant, and for providing the user with a confidence in, and control over the model, which has previously been a stumbling block in many OR implementations. (See [8] for another example of the significance of user interaction), [14].

These sessions generated a high level of commitment and interest from the client, and some lasted several hours longer than the initially planned 1–2 hours. The model produced formed the basis for discussing and developing with the client some possible strategies, for coping with the 'mess'.

SOME ISSUES IN THE IMPLEMENTATION OF SAW CUTTING PACKAGES

As Fig. 2 illustrates, a complex picture emerged around the cutting pattern problem. The problems of earlier implementations seemed to be related to attempts to solve single issues rather than look at the whole picture—for the client the cognitive map had shown this up in a particularly vivid way, even though it had been something he had partly expected. Some of the problems are described below (the relevant concepts from the cognitive map are shown in brackets).

Volume and waste

As Fig. 2 shows, minimization of waste is likely to lead to more complex cutting patterns (*waste, pattern complexity*). In general, for a given set of required panel sizes, and fixed size of board from which the panels are to be cut, greater flexibility in the number and direction of cuts, allows greater utilization of the board (Fig. 1 shows some typical patterns available to the planner). More complex patterns require more saw cuts per board (*saw cutting time*), and create additional handling and sorting problems (*handling and sorting problems*). The overall effect of these is to decrease volume throughput (*volume*). Yet historically, as noted earlier, the industries have been geared to volume as a measure of performance, e.g. most bonus systems in the UK furniture industry still operate on this principle. It is often therefore not in the interest of the production manager or saw operators to pay too much attention to waste reduction, especially when more complex patterns lead to more difficult cutting, and decrease the number of set up and load times, and thereby reduce the opportunity to make up time on the job, (*maximum aggravation for workers*).

Waste and pattern discontinuity

Cutting algorithms have been criticized on the grounds that they produce a wider spread of panel sizes over different patterns (*panel spread*), which means that it takes longer for a complete set of panels for a given order to be ready for the next operation. There is consequently a storage problem in the mill, and a production scheduling problem for the rest of the factory, if it works on a flow line basis, (*bottlenecks*).

Waste and machine utilization

Factories are not usually in the position that they have the best saws available with unlimited capacity. More frequently a variety of saws and saw methods are available of differing ages and capabilities. Equally the sawyers are not all as able as each other on different saws. Waste minimization is in part a function of saw design, and so there is a tendency for the optimization to overload the more effective saws, (*saw design too simple, no way to get volume, machine utilization*). For example, in a more recent implementation of a package of this sort, by the client, the optimization program tended to produce cutting patterns for one saw type (the oldest) rather than the firm's newer purchase which in fact turned out to be a poor saw purchase decision for their particular needs [13].

Waste and saw design

As the preceding paragraph suggests, the introduction of computer aids to waste minimization can often reveal more deep seated problems associated with the production process, and available equipment. Implementation then becomes a much more difficult process, and chances of failure are much greater. In one implementation the eventual changes were: a new productivity scheme, a re-organization of the production line, different ways of cutting, and a new approach to job scheduling (from single job sheduling to batch).

Previously the client had used written reports, discussion papers, and arranged a series of meetings with colleagues to try and think through the issues which worried him, but with only limited success. Cognitive mapping seemed to offer a facility for stimulating thought, and recording it in a more flexible and accessible way, which enabled the client to take his thinking further than before. It provided a way of handling complex, qualitative data.

Some results for the client

By being able to dump his ideas in this way the client was able to devise some strategies for handling the mess he faced. e.g.

(a) To re-design the computer package to take account of some of the practical constraints, such as differences between saws, constraints on pattern complexity and panel spread.

(b) To make the implementation a much longer process, and to look more widely at some of the production and marketing philosophies followed by a company.

(c) Preparation of specific material which enabled some of the complex interrelated issues surrounding the cutting problem to be better appreciated by a wider audience in the furniture and packing case industries.

(d) To begin to look at the longer term implications of decision making in the area of saw purchase.

The researchers regard these steps (and there were others) and the subsequent reported improvement in implementation from the client, as indicators that the client had been able to manage his 'mess' successfully.

SOME IMPLICATIONS FOR OPERATIONAL RESEARCH

Whilst the project was primarily concerned with assisting a decision maker with a complex issue which he felt he faced, the content of this issue concerned the implementation of OR ideas in a practical setting. The final section therefore discusses some of these issues which may be of wider significance to OR workers.

The principal concern highlighted by the client was that the traditional technical approaches to this problem were, on their own, unable to assist him (a practitioner) in the implementation of an OR approach to an industrial problem. If OR is to maintain its claim to be of practical benefit then perhaps a wider context for OR work needs to be fostered.

'Classical' OR

The words 'on their own' are crucial. since it is clear that without the mathematical and technical work that has gone into cutting algorithms (including linear programming, dynamic programming, ingenious heuristics) compact mini-computer based approaches would not be available [9, 10, 11, 15]. It is equally clear though that the client in this project, and a number of those involved in the furniture industry, felt that the technical work was inaccessible to them, and it also lost much of its credibility by discussing what were to them obviously 'stupid' notions, such as non-orthogonal cutting. Also there was a tendency for those involved in the early implementations to restrict their view of the problem to technical issues. Clearly some of the practical constraints can be included by alteration of the objective function of the program, but as the issues raised earlier indicate there are other industrial peculiarities and characteristics to be considered.

Demythologizing OR

As Dando & Sharp [4] point out, the myth of OR as a hard science ignores much of what OR workers do, and incidentally much of what science in the Twentieth Century is about [17]. The science myth unfortunately points both OR workers, and those in receipt of OR in the direction of well defined problems and neat solutions, yet as much of this paper has been attempting to convey, in support of Ackoff and others, well defined problems and neat solutions do not necessarily match what individuals in organizations construe themselves to be facing. Both physically and cognitively anything worthy of calling for outside help on, is more likely to be a 'mess' than a problem. Ways of managing messes require different skills to those required for the development of cutting algorithms. For example, in this project the implementation of a computer package potentially affects a wide range of people, and physical systems, which require skills in handling complex qualitative data and interpersonal issues. Many of those concerned may perceive different issues and worries in relation to this event. Whilst they all may ascribe publicly to the 'importance of getting the waste figure down', for each it raises quite different fears.

For the production manager there is the prospect of more complex scheduling, for the mill manager problems with storage, for the operator more difficult cutting patterns, and perhaps less opportunity to earn a good bonus. Tackling these issues is a vital part of the implementation process. Whilst as Stainton hints in his two very different papers on the same project, it may be that OR workers do all this, but feel constrained by the myth not to write about it [19]. We suspect that as OR grows as a discipline, interdisciplinarity is rapidly fading [18]. Consequently particular OR skills are emphasised at the expense of others. As recognized OR skills change, then the nature of the OR task also changes since it is in part determined by the skills OR workers present, and the skills which potential clients perceive them to possess. This project illustrated more clearly than many others the importance of both technical skills, and skills concerned with managing qualitative data and interpersonal issues. We hope we have been able to describe how these different skills need to link for successful OR.

Perhaps it is because these latter skills for handling qualitative complex issues are less readily slotted into a particular scientific method that they receive less attention in the OR literature. But in as much as OR is concerned with making ideas work in practical settings we believe, and our experience in this project supports this, that these other skills are an equally important part of Operational Research.

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REFERENCES

1. ACKOFF RL (1979) The future of Operational Research is past. *Jl Opl Res. Soc.* 30(2) 93-104.
2. ACKOFF RL (1979) Resurrecting the future of Operational Research. *Jl Opl Res. Soc.* 30(3) 189-199.
3. ADAMOWICZ M & ALBANO A (1976) A solution on the rectangular cutting-stock problem. IEEE Transactions on Systems, Management, and Cybernetics. *SMC* 6(4), 302-310.
4. DANDO MR & SHARP RG (1978) Operational research in the UK in 1977: The causes and consequences of a myth? *Jl Opl Res. Soc.* 29(10), 939-949.
5. EDEN C, JONES S & SIMS D (1979) *Thinking in Organizations*. Macmillan, London, UK.
6. EDEN C & SIMS D (1979) On the nature of problems in consulting practice. *Omega* 7(2), 119-127.
7. EDEN C, SMITHIN T & WILTSHIRE J (1980) Cognition, simulation and learning. *Jl Exp. Learn. Simn.* 2, 131-143.
8. ELDER M (1980) A tool for learning to understand the problem. Presented at The Young OR Conference, Stoneleigh, Warwickshire, UK. December 2-4.
9. GILMORE PC (1979) Cutting stock, linear programming, knapsacking, dynamic programming and integer programming, some interconnections. *Ann. Disc. Math.* 4, 217-235.
10. GILMORE PC & GOMORY RE (1965) Multistage cutting stock problems of two and more dimensions. *Ops Res.* 13, 94-120.
11. HAESSLER RW (1980) Solving the two stage cutting stock problem. *Omega* 7, 145-151.
12. HARRISON P & HOLLAND J (1979) How do furniture companies make operational decisions? *Furn. Manr.* January, 32-34.
13. HARRISON P & SMITHIN T (1981) Boxing clever. Working Paper, University of Bath, UK.
14. HEWITT M & SMITHIN T (1981) How to cope: Managing with Computers. *Comput. Age.* 14, 82 84.
15. HINXMAN AI (1980) The trim-loss and assortment problems: a survey. *Eur. Jl Opl Res.* 5, 8-18.
16. JACKSON JR (1974) Coping with complexity. Mimeograph. University of California, Los Angeles, USA.
17. MAJONE G (1980) Policies as theories. *Omega* 8, 151-162.
18. SIMS D (1981) The practice of OR. *Mgmt Dec.* Forthcoming.
19. STAINTON RS (1979) Modelling and reality. *Jl Opl Res. Soc.* 30(12), 1031-1036.

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******* PUBLISHED PAPERS *******

[2]. A Multi-Objective Decision Problem: The Furniture Manufacturer's 2-Dimensional Cutting or Trim Problem:

Short Paper presented at the I.M.A. International Conference, Manchester, England 1982.

A MULTI-OBJECTIVE DECISION PROBLEM: THE FURNITURE MANUFACTURER'S 2-DIMENSIONAL CUTTING OR TRIM PROBLEM

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BACKGROUND TO THE PROBLEM

Since 1978 we have been actively engaged in researching into the area of Operational Decision Making within the wood based industries in the U.K., Sweden, Finland and the USA. Part of this research has centred around the operational decision associated with cutting the large, predominately rectangular, boards into the smaller panel sizes required within the manufacture of furniture, i.e. the well known cutting or trim problem (2DCP).

The Furniture Manufacturer's 2DCP requires the conversion of large, composite, board materials into the smaller "sized" panels which are then subjected to additional manufacturing operations before they are assembled into (a) units of furniture, or (b) packed, to be despatched as DIY self-assemble kits of furniture. The sawing technology and the "box-like" design of modern day furniture constrains the sawing operation to guillotine cuts only. The cutting operation can be considered as a two or three staged process. The first stage is to cut the board into length strips. The second stage is to cut across these length strips thereby effecting an actual panel - smaller rectangle or square size. The third stage, known as off-line cutting or Z cutting, occurs when an additional cutting operation has to be performed, after stages 1 and 2, to obtain the correct panel size. In addition, the Planner (decision maker - DM) also has the option of Head-Cutting. If the H-Cutting option is taken, then the first cut will be across the width of the board. Thereafter the two "smaller" boards are machined separately.

APPROACHES TO THE CUTTING STOCK PROBLEM

The majority of the published work on the cutting stock problem has focused attention on the one and two dimensional trim problems of the paper, glass and steel industries, only minor references having been made to the furniture industries 2DCP. In this published work to date, the general emphasis has been clearly toward defining the problem as having a single objective function, i.e., that of waste minimisation. However, although there appears to be an abundance of mathematical solution methods available to solve the 2DCP, the number of companies actually using computerised approaches are few. The main reason we suggest for this is centred around the fact that the current solution methods only satisfy a small proportion of the Planner's actual cutting problems. Even where sophisticated multi-objective linear programming solutions, which incorporate novel back tracking sub-algorithms, are used the computerised results are rarely better than the manually generated cutting patterns of the Planner.

A MULTI-OBJECTIVE PROBLEM: WASTE AND OTHER CONSEQUENCES

During our research it has become evident that the Furniture Manufacturer's 2DCP cannot be formulated and solved as a normative trim-loss problem, where the predominant goal is one of waste minimisation. In practice the Furniture Manufacturer's 2DCP encompasses a complex, inter-related, set of problem issues which require wastage and other consequences to be considered. These "other consequences" include:

- costs associated with edge waste;
- cutting costs associated with level of complexity of cutting patterns;
- volume throughput (i.e. the amount of m^3 cut per hour):
- number of cutting patterns to number of panel inputs;
- the spread of panels (i.e. panel "A" appearing on too many cutting patterns).

The main objective of the Planner is to generate cutting patterns which satisfactorily take account of these consequences and other industrial characteristics, whilst maintaining a balance between them all, rather than optimising one objective at the expense of the remainder.

THE PLANNERS PREFERENCE SYSTEM

It is tempting to suggest that these other consequences can be treated on similar lines to multiple-attribute decision making. That presupposes, however, that the Planner can fully identify the attributes of the problem and that these attributes fully describe his goals. As we have discovered, Planners do not think in such terms. Determining the number and type of attributes that will describe an alternative is a difficult and complex task; even more so when the problem is complex and as inter-related as the 2DCP. If we assume that the attributes that the Planner focuses on are determined by his underlying goal structure, the problem still remains of how to identify and measure these values. Clearly one approach could be the use of numerical scales. However, although making the problem somewhat easier to deal with, not all the consequences of the 2DCP are easily formulated into scales of numerical values. In addition our research has shown that Planners are basically non-numerate, in the mathematical sense, and often have difficulty in verbalising their value system of preferences.

TRADE-OFF APPROACH

Where it is difficult to relate nominal and numerical attributes, suggestions in the literature advocate that the problem be structured using the concept of trade-offs. For example, in the 2DCP this could be achieved by considering the change in waste costs that would be required for a given change, in say, the reduction in the number of cutting patterns, i.e. the notion of trade-offs between differing sets of cutting patterns which produce the same set of panels. However, in practice it is not that simple. In our research we have found that Planners' preferences and the trade-offs upper and lower bounds, tend to change given certain circumstances. For example, the starting goal is just as likely to be the minimisation of the number of cutting patterns as the minimisation of waste. This preference for a low number of cutting patterns may be modified, even discarded after the generation of the first few cutting patterns, the explanation for this simply being that the possibility of cutting patterns with high order closures existing is greatest at the start point, not half way through the pattern generation routine. Given that the Planner has, in these initial few cutting patterns, sacrificed potential savings in material costs for high panel order closure per cutting pattern, then the over-riding objective would now become one of waste minimisation. This would then require that a new set of preferences, centred around the waste minimisation objective be adopted.

A PARAMETERISED APPROACH

Planners, then, do not use just one set of ordered preference values in sorting through their cutting problem, but many. More importantly, the ordering of these preferences and the level and activity of trade-offs between them tend to change, dependent upon the actual position that the Planner perceives himself to be in, i.e., if there is pressure from the Production Manager for increased volume, due to high product demand, then the waste objective might very well be modified for an increase in volume throughput. Thus, although the concept of simple preferences and trade-offs between two or three alternatives is theoretically easy to handle, in many practical cases, as the 2DCP indicates, this is likely to be unrepresentative of the actual decision situation faced by the decision maker.

In practice we find that decision makers require to be able to direct the problem solution, i.e., if volume is the primary goal then the solution approach has to rank the other consequences in relation to this goal and then determine the solution. Often only part of the solution is acceptable and hence the offending solutions are required to be re-calculated with the initial goal being ranked lower. The problem solution then is derived from successive iterations, each iteration imparting additional information which may or may not result in the decision maker restructuring the actual problem.

Given this situation, our approach to structuring the decision maker's preference system was to parameterise the main objectives and consequences and to allow the decision maker to select interactively his preferred solution direction. At this stage we add that our results are encouraging in as much as the parameters allow the decision maker to approach the cutting problem from a variety of different goals. Also the Decision maker is in control of the direction of the eventual solution - not the programme - and it is probably this aspect of our approach which has resulted in our successful implementation record. We now proceed to detail our heuristic approach to the Furniture Manufacturer's 2DCP.

AN INTERACTIVE HEURISTIC APPROACH TO THE 2DCP

Central to our approach to the Furniture Manufacturer's 2DCP is the belief that the real decision problem confronting the Planner is far more complex than the normative 2DCP cited in the literature. Furthermore, our experiences, gained from numerous installations, suggest that Planners require help and support to sort through the conflicting, inter-related set of objectives, not answers which claim to be optimal from a pure mathematical standpoint. What has to be understood is that the 2DCP affects a wide range of decision makers within the same system, and although there may be a general consensus about the necessity to minimise the wastage within the cutting operation - the rational economical objective - for each decision maker the 2DCP will raise quite different issues. High cutting pattern complexity, for example, means different things to different decision makers. For the Production Manager there is the prospect of less volume, due to high cutting pattern complexities; for the Planner, the complexity of the sequencing of panels which are spread across the complex cutting patterns; for the Mill Manager, a no win situation where no single objective has preference; all are equal! For the Sawyer, complex cutting patterns equate to more aggravation, not less, and the Purchasing Manager, who views the problem as one relating to material costs and order processing issues.

THREE STAGES

The approach that has been developed and which is now briefly outlined consists of three stages and follows very closely the heuristic methods and ideas that are used and which work in practice.

Stage 1 - User Defined Patterns

It became evident from our research that Planners stored, at a sub-conscious level, sets of good cutting patterns, good meaning acceptable wastage levels, high order closure per pattern with high or low open orders. When presented with a cutting list that required cutting patterns to be calculated, Planners automatically scanned the order listing in an attempt to identify and match orders to their library file of good cutting patterns. Often subtle changes would take place to the order list - in effect a relaxation of some of the restrictions - so that these good cutting patterns could be utilised. This pattern matching first stage then goes some of the way in explaining why manual approaches generally result in less cutting patterns, with slightly higher wastage levels, than the computer generated solutions. Quite simply, the objective function, at the initial stage is to select cutting patterns that close a high proportion of the order list and have acceptable levels of waste. Subsequent iterations will have less combinations that will satisfy these two goals and hence wastage levels will inevitably become the dominant goal. Having unearthed this User Defined Approach it seemed correct that the first stage of our algorithm should have a User Defined Routine so that the Planner could easily define his good cutting pattern set and store for later use, if required. Hence the first stage of our approach is an interactive User Defined pattern routine. In this routine the Planner is able to input his initial good set easily and to modify that set to reflect the current order requirements. Typically the current order requirement is matched to this set of good cutting patterns and then the order list is decremented.

Stage 2 - Strip Generation

The second stage of the algorithm is the generation of strip candidates to match the order requirements, i.e. it is necessary to determine the possible partitions of the panel lengths - and widths if there is no grain direction - into the given board lengths. To limit the generation to only feasible strip combinations a set of strip parameters is used. The concepts of additional panel inclusion and open orders are formally incorporated into the evaluation of the strip candidates by the use of a mathematical expression which allows the non-linear aspects of the 2DCP to be introduced explicitly into the evaluation procedure. These non-linear aspects are parameterised within the programme and are controllable by the Planner.

Stage 3 - Cutting Pattern Enumeration

The third stage is the enumeration of the cutting pattern. This uses the previously generated and evaluated strip candidates from Stage 2. Once again the concept of a cutting pattern value, similar to the one for strips, is used to generate and evaluate the best cutting pattern combination. The panel order list is then decremented and lexico-graphically re-ordered. The algorithm continues in this iterative manner, with alternative second and third stages, until the order list is satisfied, i.e. a problem reduction method. As many readers will no doubt realise, the problem reduction method can often result in the later cutting pattern tending to have higher waste and often low quantities of boards, i.e. unacceptable solutions. These patterns, which tend to exist in practice, force the Planner to adopt certain strategies to make these cutting patterns more acceptable, i.e.

- an additional panel type not previously included in the order list may be brought into consideration ... or
- accept higher amounts of extras ... or
- be prepared to use a different board size than initially stated ... or
- cancel the offending panel order - if possible

and there are other strategies.

Stage 1 then offers the Planner the facility to amend these poorer, later cutting patterns, and hence the major problem associated with the problem reduction method does not arise.

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[3]. Cutting Through Problems:

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The Successful Application of Operational Research Techniques in Solving the Furniture and Packing Case Industries Trim Problem.

by Paul Harrison 1982.

INTRODUCTION.

For some years now we have been concerned with developing and implementing solutions to the two dimensional cutting problem as found in the Furniture and Packing Case Industries.The major raw materials used by the Furniture Manufactuer is chipboard whereas the Packing Case industry use plywood in varying grades and thicknesses.These basic raw materials account for 40% to 60% of the total product cost for the Furniture and Packing Case manufacturer,respectively.Not surprisingly therefore,decisions relating to the purchase of these raw materials and their subsequent conversion can have a significant effect on the overall profitability of the company.

In this paper,we describe a trim problem of a Packing Case Manufacturer.The case study illustrates more clearly than many others the importance within Operational Research of combining the technical skills and the skills concerned with managing qualitative data and interpersonal issues.For example,many of those concerned with the trim problem perceive different problems and issues.Thus whilst they all may openly ascribe to the importance of getting the wastage figure down,for each person the goal of waste minimization will have a different meaning.

THE COMPANY.

Sumacon Luralda,are a subsidary company within the M.L.M.Packaging group of companies.They manufacture plywood and heavy duty corrugated carton packing cases for various uses,on a made to order basis.Typical product examples are overseas and automotive packing cases.The major raw material used in the manufacturing process is plywood in varying grades of quality and thicknesses.In general the work undertaken by Sumacon,can be divided into two groups,namely,Contract and Non-contract work.These are now briefly described.

Contract Work:This type of work is available to all Case Manufacturers and is bid for on a contract by contract basis.The contract defines the size of the packing case,the quality of the materials to be used and the date required.Typical sources of contract work are the M.O.D. and overseas packing cases for car components.As the contract is for a fixed period;generally a year,this type of work tends to generate a lower profit figure per unit of output than the Non-contract work.

Non-contract Work:This type of work is subject to the plaquerisms of the demand within the current market place and as such Sumacon,compete with other Packing Case Manufacturers for orders on a day to day,week to week basis.Due to the variance between the revenue/profit generating power of the two order types,the Contract work can and sometimes is used as a productive volume regulator.ie.when the Non-contract work load is low then the contract work can be pulled forward to fill the output gap.This juggeling of orders and the resultant mixing of the order sizes and quantities is of significant importance when considering the residual problem of an order appearing on too many cutting patterns.

MANUFACTURING CYCLE.

Within the manufacturing cycle of plywood packing cases,there are three specific functional areas to consider:
(1).The Mill;
(2).The Print Section;
and
(3).The Assembly Section.

AREA 1.The Mill or Primary Conversion Section:This in effect is the heart of the system,the area in which the raw material - plywood sheets of varying sizes and thicknesses - are converted into the smaller square or rectangular shaped panels,which are required for the packing cases.This conversion process is carried out on a weekly basis;ie.orders are batched a week in advace of their requirement.Hence there is generally a weeks buffer between the Mill and the Print section,area 2.

AREA 2.The Print Section:The function of the Print section is as it's name suggests:ie.Dependent upon the eventual usage of the packing case,certain shipping marks,company loggo's or custom and excise marks may be required to be printed on one or more of the panels which go to make up the packing case.During our initial investigation it was noted that approximately sixty percent of the cut panels miss the Print section and go direct to the Assembly section,area 3.

AREA 3.The Nailing,Riviting and Assembly Section:The final series of operations in the manufacturing cycle is the nailing,riviting and the assembly of the cut panels to form the complete packing case.Dependent upon the the packing case usage/design,the ends and sides will be closed by wooden or metal corner pieces.It is of major importance therefore that the respective matched sets of ends and sides arrive at area 3,from areas 1 and 2,together.

PRIMARY DECISION AREA.

Although all the areas are obviously important in the manufacturing cycle,the area of significant importance is area 1,the Mill or Primary Conversion operation.The major reasons for this are:

(1).The Mill is the base from which all other manufacturing decisions eminate.In practise decisions on what to do,when to do it,and the planning and matching of requirements to resources are invariably taken from the generated cutting patterns.The cutting pattern determination in effect is the primary decision for the whole system.

(2).For most companies the purchase of raw material constitutes a considerable and increasing cost.In plywood packing cases for example the material cost can be as high as sixty percent of the total selling cost.The saving of material therefore can significantly effect the overall profitability of a company.In addition,the reduction of material costs can also result in the ability to offer a lower product cost to the customer;a marketing plus for a company who are competing against others,in the market place for orders.

MINIMIZATION OF MATERIAL USAGE.

The initial problem identified by the management within Sumacon was one of high material wastage.In an effort to increase the order yield from the various plywood sheet sizes available a computerised solution approach ,for cutting patterns was sought.The only initial managerial objective set was that the computer system should result in reduced material usage.ie.the minimization of waste or edge trim loss.It was agreed therefore to run the proposed system in parallel with their manual system for a period of three weeks.The positive outcome from this benchmark test,as shown in table 1,justified the continuation of the analysis as the cost of the proposed system would be paid for in less than twelve months.

PRACTICAL CONSIDERATIONS.

From a practical view point however,there were considerable differences between the results of the computerised and manual approaches.In the computer model the following practical issues were not considered:

(a). Board availability not restricted;assumed that there were infinite boards available.

(b). Cost associated with the cutting operation not considered.

(c). No consideration was given to the sequencing of the orders.This resulted in the panel requirements for a specific order being widely spread throughout the cutting patterns.

(d). The implications on the volume throughput for the Mill and the company in general was not considered.

(e). The effect of pattern complexity on the setting times for the different sawing machines was not taken into consideration.

(f). No account was taken of the priority of the different orders.ie.not all panel sizes and quantities have the same date of dispatch and as such the orders are required to be processed in some priority,which in turn has to be matched to the available machinary resources of the Mill.

(g). Restrictions on the level of pattern complexity were not considered by the programme.

From a bottom-up view-point then many of the industrial characteristics had not been considered and as such although the computerised cutting patterns were feasiable,they were practical unusable.Although aware of these shortcomings, in the model,the management of Sumacon were impressed by the performance of the computerised approach and were also awakened to the possible benifits that might be achieved from using an Operational Research approach to their trim problem. The next stage in the developement of the computer model therefore was to spend considerable time with the Mill manager,so that the industrial characteristics of the cutting operation could be understood and incorporated into the computer model.

DECISION CRITERIA USED BY THE MILL MANAGER.

The start point in the elicitation stage was to highlight and discuss the previously identified inadequacies of the computer model with the Mill manager.During these general discussion periods it became quite clear that two different objectives were being pursued at different times within the same week,by the Mill manager;namely volume maximization and waste minimization.The explanation given by the Mill manager for this was:

"..... obviously I'm concerned with wastage,however its also important that all the lads are working.Therefore on Monday,the start of the batch,a number of cutting patterns,which result in high runs are calculated quickly.My main concern is to load the Panel Trim saw (the primary sawing machine) for three to four hours.This occupies three sawyers and starts to provide work for the Cross-cut and Dimension saws.In addition it is quite normal that small runs or re-cuts from the previous week may be required.These short term jobs are allocated to the remainder of the sawyers which gives me a few hours to sort out further cutting patterns.By Wednesday,there are generally a lot of off-cuts,both in terms of numbers and sizes.This isn't surprising as some of the cutting patterns at the begining of the week probably had only one panel on them,hence the large off-cut.These large off-cuts are then used to cut the smaller sized cases,or the tops and bottoms for the medium sized cases.The end result is that our wastage figures aren't too bad....certaintly its below the costed figure."

This pre-occupation to the volume variable rather than to the material wastage criterion of managements caused rather a surprise when related to the Production Director.However given that the Mill manager and the Sawyers measurement of performance was based on the volume variable, the degree of importance afforded to the volume variable was understandable.This discovery lead to certain changes being made in the evaluation of departmental and operative performance and also highlighted the mis-matched goals and objectives between the Mill manager and his Production Director.

MODIFICATIONS TO THE COMPUTER MODEL.

The computer model used was simarilar to the programming approach advocated by Gilmore and Gomory (1,2,3).However to take into consideration the non-linear industrial characteristics of the trim problem it was necessary to add to the linear programme a purpose built knapsack algorithm(4). This enable the following characteristics to be included in the model:

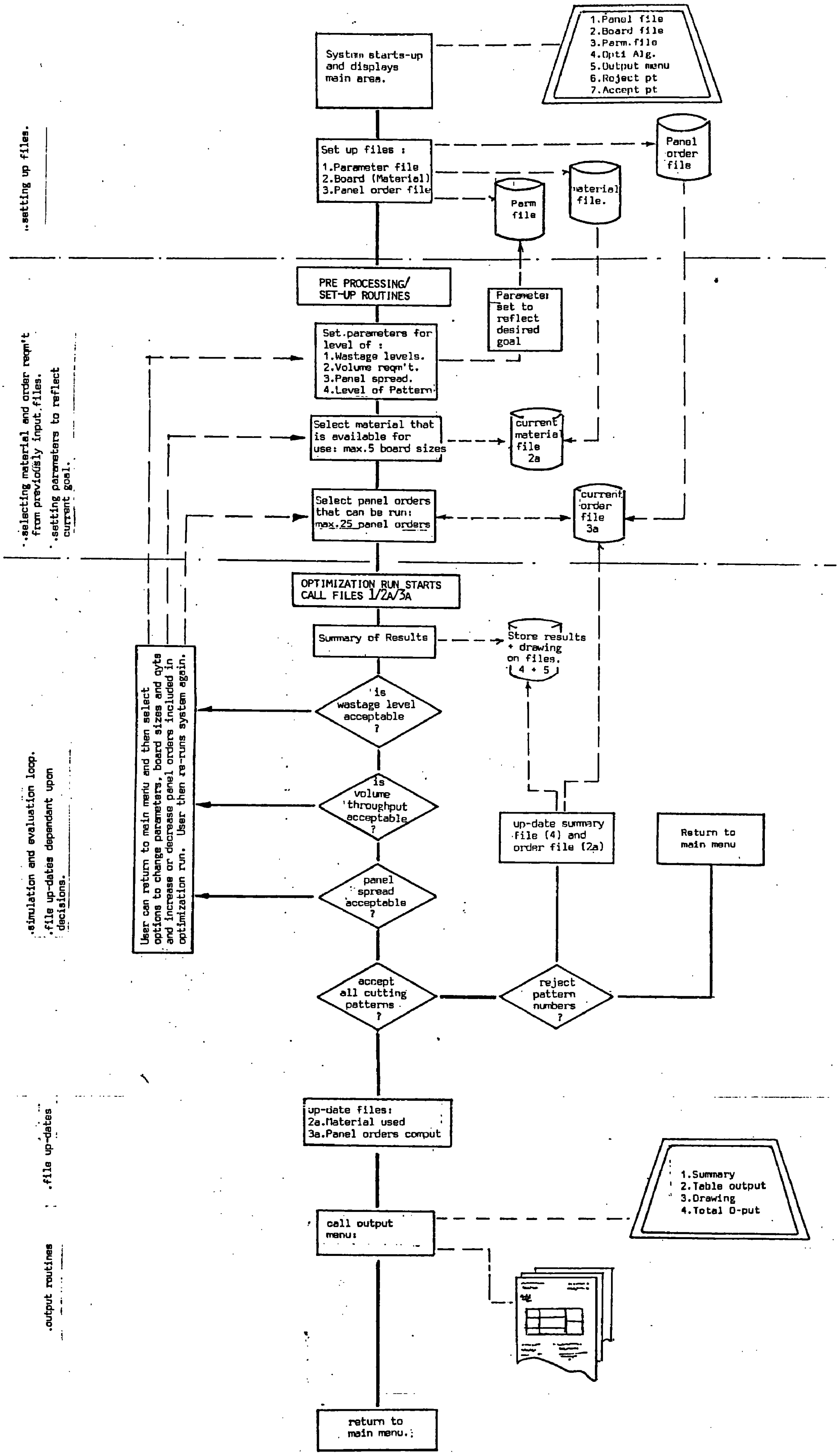
(a).Fixed quantities of boards to be specified.

(b).Upper and lower bounds were incorporated into the pattern generation routine to take account of the various sawing machines characteristics.

(c).A value heuristic was incorporated into the programme to regulate the amount of extras produced.

(d).A value heuristic was also incorporated into the strip formulation part of the programme,such that the cost of cutting could be indirectly considered and traded off against the reduction in material usage,for that pattern.

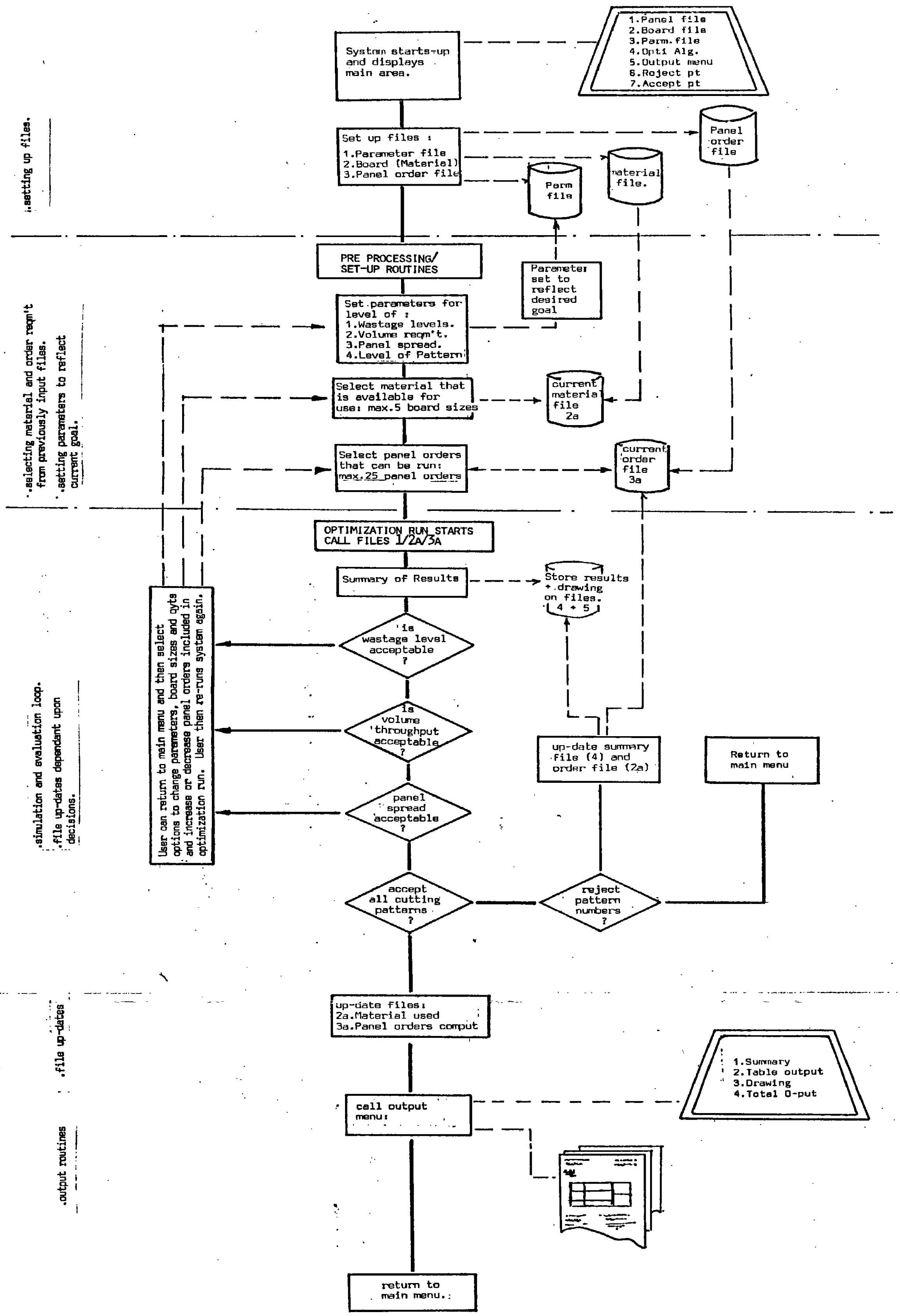
(e).The sequencing of the orders proved to be impossible to take into account due to the two staged nature of the model.ie.first strips are generated and stored,secondly,the strips are loaded into the knapsack to maximise the total value.The approach adopted therefore was to allow the restriction of the number of different panel types on one cutting pattern.This indirectly,when combined with the additional value heuristics,constrained the panel spread.If the resultant wastage figure was too high,the Mill manager could quite easily adjust the parameters within the programme and repeat the optimization run again.until a satisfactory result was obtained.ie.in effect a simulation and evaluation loop.



System starts-up and displays main area.
1.Panel file
2.Board file
3.Parm.file
4.Opti Alg.
5.Output menu
6.Reject pt
7.Accept pt
.setting up files.
Set up files :
1.Parameter file
2.Board (Material)
3.Panel order file
Panel order file
material file.
Parm file
PRE PROCESSING/ SET-UP ROUTINES
Parameter set to reflect desired goal
Set.parameters for level of :
1.Wastage levels.
2.Volume reqm't.
3.Panel spread.
4.Level of Pattern
.selecting material and order reqm't from previously input files.
.setting parameters to reflect current goal.
Select material that is available for use: max.5 board sizes
current material file 2a
Select panel orders that can be run: max.25 panel orders
current order file 3a
OPTIMIZATION RUN STARTS CALL FILES 1/2A/3A
Summary of Results
Store results + drawing on files. 4 + 5
User can return to main menu and then select options to change parameters, board sizes and qyts and increase or decrease panel orders included in optimization run. User then re-runs system again.
is wastage level acceptable ?
is volume throughput acceptable ?
panel spread acceptable ?
.simulation and evaluation loop.
.file up-dates dependent upon decisions.
up-date summary file (4) and order file (2a)
Return to main menu
accept all cutting patterns ?
reject pattern numbers ?
.file up-dates
up-date files:
2a.Material used
3a.Panel orders comput
call output menu:
1.Summary
2.Table output
3.Drawing
4.Total O-put
.output routines
return to main menu.

(f).To facilitate the simulation procedure described in (e) an Accept/Reject loop was added to the programme.This allowed the Mill manager to reject specfic cutting patterns that were unacceptable,for whatever reason;pattern run length too low,wastage too high.

Figure 1 shows,in flow chart form,the general structure of the computer model.



DIFFERENT ISSUES.

The implementation of a computer system for cutting pattern generation affects a wide range of people and physical systems.This requires skills,not only in handling complex qualitative data but also the ability to handle the many interpersonal issues which will arise.Whilst publically all the interested parties may agree the importance of getting the wastage figure down,for each it will raise different fears and anxities For the Production Director,the prospect of lower volume; increased difficulties in sequencing ; the requirement to balance labour costs against the savings in material costs.For the Mill manager,problems of split jobs;difficulties arising from set to run times and the spread of panels over too many different cutting patterns.For the Sawyer,the aggrevation of short run jobs which could lead to a reduction in bonus earnings.The necessity to understand and take account of these interpersonal issues then is as vital a part of the Operational Research process as the other,more reported mathematical construction and modelling phases(5).

The cutting of stock,like so many other managerial decisions does not involve a clear cut choice between simple alternatives but rather the reconciliation of alternatives which conflict with one another.In determining cutting patterns the Mill managers reality will vary on a day to day week by week basis.This reality will be fashioned in part by his own peer group and in part by the system environment.ie.the product orientation,the manufacturing processes and the current sales order level within the company.

The goal is to generate cutting patterns which satisfy some practical requirements,often production orientated,whilst maintaining a balance between the following operational cost areas:

(1).Edge waste costs.

(2).Cost of cutting.

(3).Volume throughput.

(4).Number of cutting patterns to panel order input.

(5).Handling and storage costs.

(6).Panel spread.

CONCLUSIONS.

The trim problem of the Furniture and Packing Case Industries then cannot be simplistically modelled as having only the single objective function of waste minimization.Other operational constraints and industrial characteristics have to be understood and included in the solution,if a meaningful and practical result is to be achieved.Since 1979 we have sucessfully developed and implemented computerised cutting solutions to the three main wood based factories within the M.L.M.group.In addition,three major furniture companies also use our computerised cutting programmes.The current estimated cumulative financial savings to these companies is in excess of £400,000.

ADDITIONAL ADVANTAGES:

The graphs in figures 2 and 3 indicate the additional yeild gained and the cost benifits associated with the introduction of the computerised approach to cutting patterns for Sumacon.Other managerial advantages that were gained by the introduction of the computerised approach were:

(1).Increased competitivness in the pricing of work.

(2).Initial cost saving due to reduction in material costs.

(3).Reduced off-cut stock holding.

(4).Enabled managerial controls on actual wastage cost to be established .

(5).Provide a managerial tool to evaluate the purchasing of the most econmical sheet sizes;and also provided a desion analysis tool for the evaluation and bidding of contract work.

(6).Made management more aware of the significance of the material wastage costs in advance of the cutting operation.This enabled production batches to be modified thereby reducing wastage even further.

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REFERENCES.

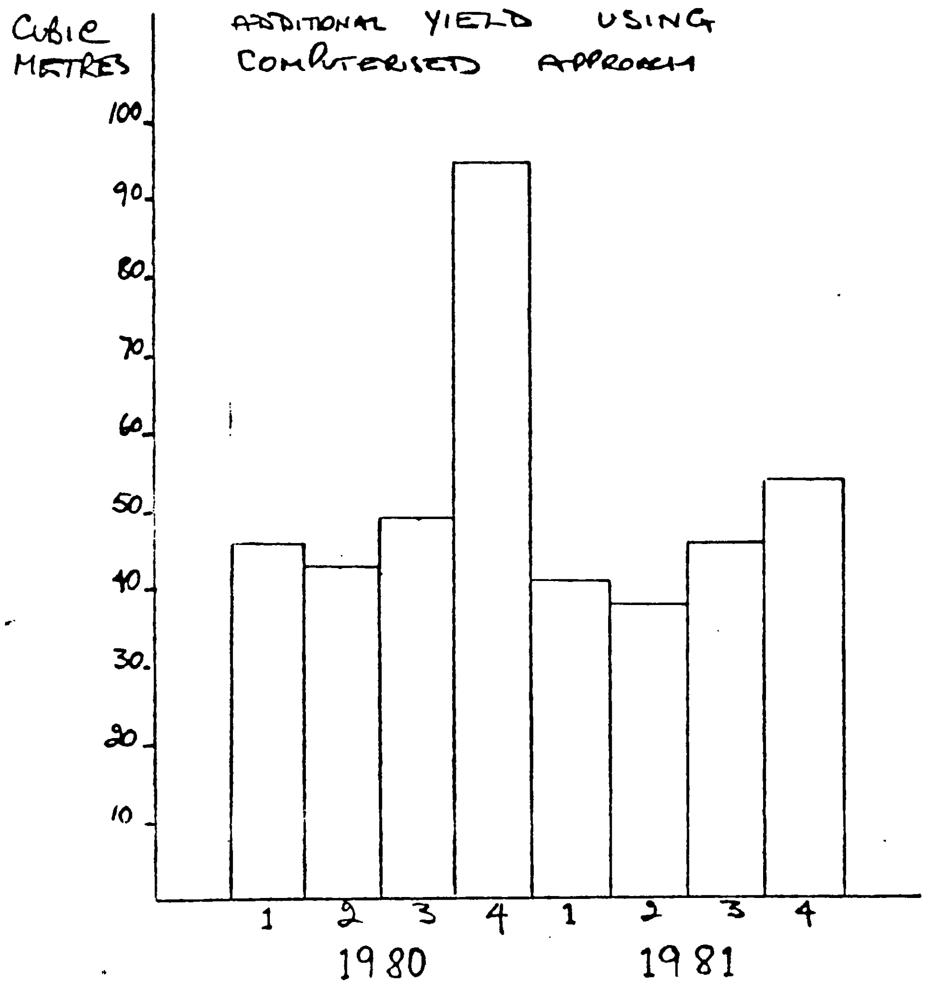
(1).P.C.Gilmore and R.E.Gomory, "A linear programming approach to the cutting stock problem.-Part I." Oper.Res.,vol 9.pp849-859. 1961.

(2).------------ "A linear programming approach to the cutting stock problem.-Part II." Oper.Res.,vol 11.pp863-888.1963.

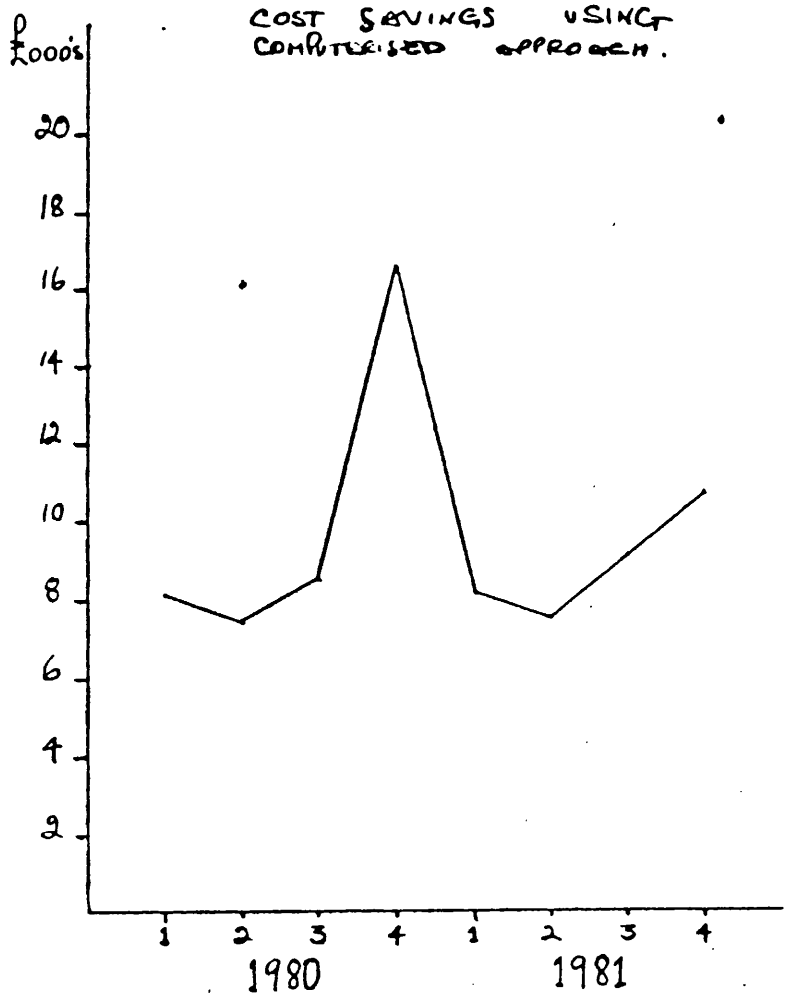
(3).------------ "Multistage cutting stock problems of two and more dimensions." Oper.Res.,vol 13 pp 94-128 1965

(4).P.Harrison and M.Suomiaen. "Working Papers on Trim Problems:AB Iggesund Bruk Sweden." 1979-81.

(5).P.Harrison and T.Smithin, "The third dimension of two dimensional cutting." The Int.Jl of Mgmt Sci.vol 10 no.1. pp 81-87 , 1982.



Cubic Metres
ADDITIONAL YIELD USING COMPUTERISED APPROACH
100
90
80
70
60
50
40
30
20
10
1
2
3
4
1
2
3
4
1980
1981



£000's
COST SAVINGS USING COMPUTERISED APPROACH.
20
18
16
14
12
10
8
6
4
2
1
2
3
4
1
2
3
4
1980
1981

	FIRST WEEK 10.4.70						SECOND WEEK						THIRD WEEK					
	4mm		5mm		6mm		4mm		5mm		6mm		4mm		5mm		6mm	
PANEL M2	3684		8865		1926		3289		4028		4243		3090		3714		3229	
	MAN	COM	MAN	COM	MAN	COM	MAN	COM	MAN	COM	MAN	COM	MAN	COM	MAN	COM	MAN	COM
BOARDS M2	4228	3857	10048	9540	2995	2500	3872	3555	4573	4502	5623	5037	3659	3368	4340	4142	4492	4076
WASTE %	14.7	4.7	13.0	7.5	55.0	29.7	17.7	8.0	13.5	11.7	32.5	18.7	18.4	8.8	17.0	11.3	39.0	26.0
Allowing usage of Off cut waste %	13.7	4.7	10.0	7.5	36.0	25.0	14.6	8.0	12.0	11.3	18.7	16.9	17.0	8.8	17.0	11.3	23.0	16.5
DIFFERENCE £££	+243	0	+248	0	+241	0	+165	0	+28	0	+81	0	+189	0	+211	0	+233	

TABLE 1.0 COMPARISON BETWEEN COMPUTER AND MANUAL SYSTEM.

REFERENCES

1.	Radford P	Cabinet Maker, Centenary Issue Mar.1982
2.	Haessler R W	The Corrugator Trim Problem. Paper presented at the 1977 Joint Nat.ORSA/ TIMS meeting in Atlanta U.S.A.
3.	Haessler R W	Solving the Two Stage Cutting Problem. OMEGA. The Ins.J. of Mgmt Sci.Vol 7.No.2 pp.145 to 151.
4.	Pierce J F	Some Large Scale Production Scheduling Problems in the Paper Industry. Prentice Hall Eng.Cliffs N.Y. U.S.A.
5.	Hahn S G	Optimal Cutting of Defective Sheets Ops.Res. 16 (1968) pp 1100-114
6.	Dyson R G and Gregory A S	The Cutting Stock Problem in the Flat Glass Industry. Ops.Res.Quar.25 (1974) - 41-53
7.	Eilon S	Optimising the Shearing of Steel Bars. J.Mech.Eng.Sci 2 (1960) pp 129-142
8.	Adamowicz M and Albano A	A Solution of the Rectangular Cutting Stock Problem. IEEE Tran.Sys.Man.Cyb. - SMC 6 (1976) pp 302-310
9.	Christofides N and Whitlock E	An Algorithm for the Two Dimensional Cutting Problem. Ops.Res. 25 (1977) pp 30-44
10.	Pfefferkorn C E	An Heuristic Problem Solving Design System for Equipment or Furniture Layouts. CACM 18 (1975) pp 286-297
11.	Hinxman A I	The Trim Loss and Assortment Problem : A Survey. Eur. Jl of Ops.Res. 5 (1980) pp 8-18
12.	Jackson R E	O.R. in the Paper Industry. OMEGA The Jl of Mgmt Sci. Vol 9 No.1 pp 43-50
13.	Stainton R S	Modelling and Reality. Jl of Ops.Res. 30 (12) pp 1031 1036

14. Kantoravick L V — Mathematical Methods of Organising and Planning Production. (translation) Mgmt Sci 6 (1960) pp 366 422

15. Gilmore P C and Gomory R E — A Linear Programming Approach to the Cutting Stock Problem. Ops Res 9 (1961) pp 849-859

16. Haley K — Mathematical Programming. Wiley (1968)

17. Bleibohn and Kuhse — German Tech Engineering Jk.Ref misplaced

18. Vajda S — Readings in Linear Programming. Chap. 21. Trim Loss Reduction. Wiley (1958)

19. Eisemann K — The Trim Problem. Mgmt Sci 3 (1957) pp 279-284

20. Metzger R W — Elemen. Mathematical Programming. Chap. 8. Stock Slitting. Wiley (1958)

21. Gilmore P C and Gomory R E — A LP Approach to the Cutting Stock Problem Part II Ops.Res.II (1963) pp 863-888

22. Gilmore P C and Gomory R E — Multi-staged Cutting Stock Problems of Two or more Dimensions. Ops.Res. 13 (1965) pp 94-120

23. Kuutti M and Voutilainen R — A Discrete Optimisation Approach to the Pattern Analysis of Cutting Patterns. Paper presented at the OR Euro. Conf. (1979)

24. Gilmore P C — Cutting Stock Problems: Some Inter connections. Draft Paper and Prov.Commun.

25. Herz J — Recursive Computational Procedures for the Two Dia. Cutting Problem. IBM Jl Res Dev 16 (1972) pp 462-469

26. Marconi R — Generalisation of the Mathematical Procedure for the Solution of the Two Dim. Cutting Problem. Centro Studi IBM Pisa Tech Rep 7 (1970)

27.	Greenberg H and Hegerich R L	A Branch Search Algorithm for the Knapsack Problem. Mgmt Sci. 16 (1970) pp 327-332
28.	Nilsson N J	Problem Solving Mehtods in Artifical Intelligence McGraw-Hill (1971)
29.	Pegels	Mis placed ref. (Tappi Jk 1968 ?)
30.	Ackoff R L	The Future of Ops Res. is Past. Jl Ops.Res. Soc. 30 (2) pp 93-104
31.	Eden C : Jones S and Sims D	Thinking in Organisations Macmillian London (1979)
32.	Jackson R J	Coping with Complexity. Private communication.Asst Prof. UCLA
33.	Gowan R	Pattern Systems Inc. Private communicstion.
34.	Harrison P	Working papers: Iggusund Bruk Sweden 1978-81
35.	Harrison P and Smithin T	The Third Dimension of Two Dimensional Cutting. OMEGA The Int Jl of Mgmt Sci Vol 10 No.1 pp 81-87

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